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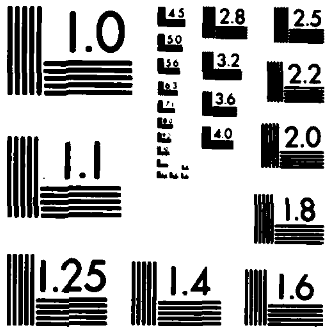

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Monterey, California

THESIS

STATISTICAL/TREND ANALYSIS OF THE
MARINE ATMOSPHERIC BOUNDARY LAYER MODEL

by

Robert D. Bisking

September 1984

Thesis Advisor: K. L. Davidson

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Transmission and reception of electromagnetic (EM) energy by communications, weapons, and active/passive sensor systems is known to be strongly influenced by an atmospheric phenomena known as ducting, caused by refractive layers in the atmosphere of marine environments. The Naval Postgraduate School (NPS) has developed a Marine Atmospheric Boundary Layer (MABL) model which can be used to predict, over a 24 hour period, the refractive profile of the lower atmosphere. This thesis examines the model from the statistical/trend

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Statistical/Trend Analysis of the Marine Atmospheric Boundary Layer Model

by

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Submitted in partial fulfillment of the requirements for the degree of

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ABSTRACT

Transmission and reception of electromagnetic (EM) energy by communications, weapons, and active/passive sensor systems is known to be strongly influenced by an atmospheric phenomena known as ducting, caused by refractive layers in the atmosphere of marine environments. The Naval Postgraduate School (NPS) has developed a Marine Atmospheric Boundary Layer (MABL) model which can be used to predict, over a 24 hour period, the refractive profile of the lower atmosphere. This thesis examines the model from the statistical/trend analysis approach to examine whether the model can be used as a valid predictor of refractive/ducting conditions.

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I. INTRODUCTION

The phenomena known as ducting occurs when refractive layers cause electromagnetic (EM) energy to bend toward the earth at a rate greater than or equal to the curvature of the earth. Ducts occur in two forms: (1) surface-based ducts caused by either a surface-based layer, Figure 1, or by an elevated layer, Figure 2, and (2) elevated ducts caused by an elevated layer, Figure 3. As shown in Figures 1 through 3, duct types and thicknesses are easily determined by utilizing the profile for the modified index of refraction M which depends on temperature, pressure, and specific humidity.

The Navy employs the Integrated Refractive Effects Prediction System (IREPS) to identify ducting conditions and to assess the effects on various fleet emitters [Ref. 1]. A drawback to IREPS usage, from a tactical standpoint, is that it depicts the ducting conditions only at the time of the radiosonde sounding.

From a tacticians viewpoint, the M-profiles are a valuable output of the Marine Atmospheric Boundary Layer (MABL) model because of the ease with which duct types and thicknesses are obtained. The frequencies which are trapped by ducts are a function of duct thickness, as

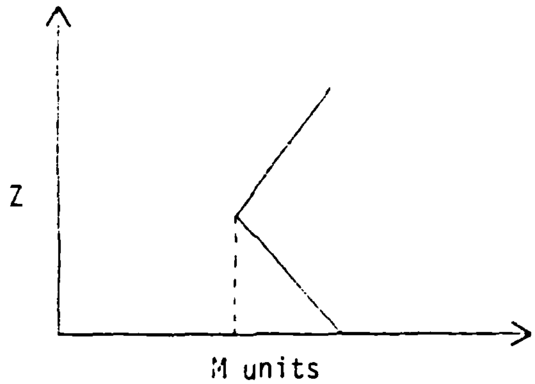


Figure 1. Surface Duct Caused by Surface-Based Layer

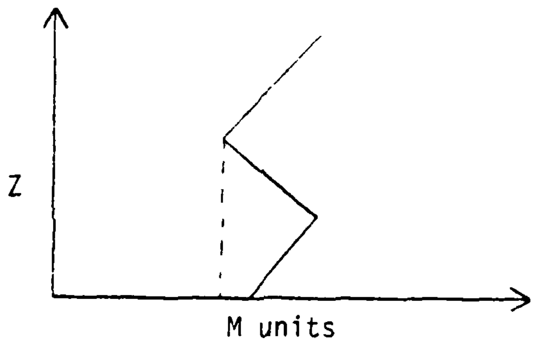


Figure 2. Surface Duct Caused by Elevated Layer

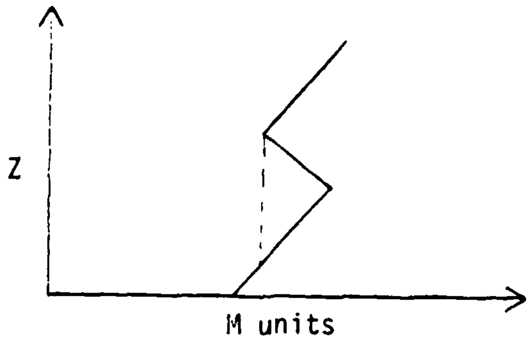


Figure 3. Elevated Duct Caused by Elevated Layer

stated by Kerr (1951). Thereby, knowing the duct thickness and type, the tactician would be able to determine the frequency range which would be trapped. In order for the EM energy to be trapped, the transmitting antenna must be physically located within the duct. Antenna heights are readily obtainable from ship's characteristic cards, hence the transmitters on board which would be affected by the duct could be quickly identified. The ability to accurately predict the evolution of the ducting conditions for a 24 hour period would be a powerful tool in the hands of today's Carrier Battle Group Commanders. This information could be used to establish Emission Control (EMCON) policy and to establish effective, efficient frequency monitoring plans. The MABL model, developed by the Environmental Physics Group at the Naval Postgraduate School (NPS), may be the medium through which this information can be made available to the fleet tacticians.

The purpose of this thesis is to perform a detailed statistical/trend analysis of the MABL to determine its validity in predicting ducting conditions for a 24 hour period. Once this analysis has been completed, conclusions and recommendations will be made in order to provide a foundation for further refining of the MABL model, if necessary, by the Environmental Physics Group. The

overall objective is to provide a reliable predictive model, available for dissemination and incorporation in the fleet.

The approach taken in this study differs from past MABL model evaluations at NPS, in that this approach is to perform an objective examination of the model. The goal is to extract information about the model output from a purely statistical/trend analysis approach, which has not been done previously.

II. MODEL DESCRIPTION

The MABL model is a zero-order, two layer, integrated mixed layer model. The atmosphere is assumed to consist of two layers: a well-mixed, turbulent boundary layer, and the relatively non-turbulent free atmosphere above. The inversion (or "transition zone") separates one layer from the other. In a zero-order model, the inversion thickness is assumed to be zero, hence, a discontinuity or "jump" occurs in the profiles of the variables at the inversion [Ref. 2].

The NPS model of the mixed-layer is implemented on a Hewlett Packard 9845 desktop computer. The model uses a 30-minute time step to predict mixed layer temperature, specific humidity, the jump of these values at the inversion, and cloud or fog formation.

The M profile is calculated from predicted T and q values using Equation (1).

$$M = 77.6(P/T) + 6 \times 10^{5} * (q * P/T^{2}) + 0.157 * Z \qquad (1)$$

where P is pressure in millibars, T is temperature in degrees Kelvin, q is specific humidity, and Z is height in meters. The top of the duct corresponds to the height above the surface where the M value is minimum. The base

of the duct is the height at which a vertical line drawn downward from the point where M is a minimum value to where it first intersects a point of equal M-units or the surface, whichever occurs first. Ducting commonly exists where there is a temperature inversion which acts as a trapping layer, refracting EM energy toward the earth. Inversions typically exist in marine surface high pressure regions where well-mixed, stable layers are found between, warm dry air above and cooler moist air below. Large areas of low level stratus clouds often indicate areas of duct occurence. Ducting is expected to be minimal near fronts and areas of convective cloudiness. Fronts, with their associated upward motion, often dissipate the inversions as the whole air column becomes mixed. Areas of convective activity, discernible by the presence of cumulus clouds, are also normally inversion free [Ref. 1].

III. CRITERIA AND ASSUMPTIONS FOR MABL MODEL VERIFICATION

A major assumption in the verification of this model is that the radiosonde data is correct. This point will be elaborated upon later in this paper.

A. CRITERIA FOR CHOOSING EXAMINATION PERIODS

Forty cases (examination periods) were chosen to evaluate the MABL model. The radiosonde soundings used in all 40 cases were taken off the coast of Southern California in and around San Clemente Island. These examination periods, which are 24 hours in length, were chosen based on the following criteria:

1. There had to be at least one radiosonde sounding in the 26 hour period preceding the examination period with surface layer data, from the NPS research vessel, Acania, within 2 hours of that sounding. This requirement is needed to calculate Ws (subsidence) with Lenschow's (1973) method.

2. There had to be surface layer data within 2 hours of the radiosonde sounding at the beginning of the examination period, also required in calculating Ws.

3. There had to be at least 2 soundings, in addition to the initial sounding, during the examination period to be used as verifications of the model's predictions.

4. Wind speeds had to be available within 3 hours of the initial sounding. If wind speeds are available within 3 hours of the 12 hour point or within 3 hours of the 24 hour point they will also be used. If these 2 values are not available, the initial value will be used and held constant during the exam period.

B. INITIALIZATION REQUIREMENTS FOR MODEL PREDICTIONS

The model requires as input data the following:

1. Radiosonde Sounding Data

Raw data from the radiosonde launches must be digitized for use in the MABL model.

2. Subsidence (Ws) Prediction

The subsidence value used in the model prediction for all 40 cases was obtained from integration of the Moisture Budget Equation given in Equation (2). This method was developed and performed by Lenschow (1973). It is based on the assumption of well-mixed specific humidity (q) in the boundary layer, and that changes occur due to fluxes at the sea surface and inversion only.

$$Ws = \frac{\Delta(q+1)\ (dh/dt) - h[d(q+1)/dt] + \overline{w'q'}(0)}{\Delta(q+1) + (\beta h/2)} \qquad (2)$$

where h is the inversion height, q and l are vapor and liquid water contents, $\overline{w'q'}$ is the moisture flux, β is the vertical gradient of $(q-l)$ in the mixed layer, and $\Delta(q-l)$ is the difference between total moisture in the mixed layer and total moisture immediately above the mixed layer. In this evaluation, the linear trend in subsidence during the 24 hour period prior to an examination period was calculated, and the regression line applied at the model start time to find the subsidence value used throughout the prediction period.

If the subsidence value was positive, then a default value of zero was used to initialize the model. A positive value of subsidence causes the model to "blow-up". The reason for this has not been determined at the time of this writing.

3. Sea Surface Temperature (SST)

This value was obtained from Acania data. The SST at the beginning of the period was held constant throughout the examination period.

4. Wind Speed

a. If wind speed was not available within 3 hours of the 12 hour point but is available at 24 hour point, then a linear regression was performed using the initial and 24 hour values.

b. If wind speed was not available at the 24 hour point, but is at the 12 hour point, a linear regression is done between the initial and 12 hour values and held constant the last 12 hours of the period.

c. If wind speed was not available within 3 hours of the 12 or 24 hour points, then the initial value is held constant throughout.

IV. STATISTICAL/TREND ANALYSIS OF THE MABL MODEL

As previously stated, the main objective of this thesis is to determine the validity/accuracy of the MABL model's ability to predict ducting conditions over a 24 hour period.

Of the 42 cases used in the verification, five cases were omitted because during the examination periods the atmosphere was stable, therefore the model physics do not apply. Seven cases were omitted because the inversion height, Zi, was less than 200 meters, for which case, the model physics do not apply. This left 28 cases to be used for the model verification. These 28 cases contain a total of 69 radiosonde soundings used for verification purposes. Although the model predicts several parameters (T,q,Zlcl,Zi) during the 24 hour prediction period, the parameter under evaluation in this thesis is the temperature inversion height, Zi, because this value is the height of the top of the atmospheric duct. If this value cannot be predicted accurately, the model is of little use to the fleet tactician.

The current method employed by Geophysics Officers afloat to predict T (temperature), q (specific humidity), Zlcl (lifting condensation level), and Zi, is

"Persistence". Persistence means that nothing changes. For example, if a radiosonde launch at 2800 indicates that the inversion height is 500 meters, then a persistence prediction would state that the inversion height would remain unchanged, until the next launch at which time it would be updated to the current value.

A. STATISTICAL/TREND ANALYSIS DATA AND RESULTS

The procedures and methods used for the statistical/trend analysis of the MABL model and persistence will now be presented.. All of the results presented in this chapter will be discussed in the chapter of conclusions.

1. Duct Trend Prediction

Prior to examining the inversion height prediction, it is important to determine how accurately the MABL model and persistence predicts the trend of existing ducts during the 24 hour examination period. Predicting the trend by the model means, for example, if an elevated duct occurs at the initial sounding and then becomes a surface based duct, does the model predict this trend? Predicting the trend by persistence involves looking at the radiosonde launch immediately prior to the initial sounding and observing the trend. For example, if the inversion height is decreasing during this period then it is assumed,

by persistence, to continue to decrease during the examination period. This segment of the evaluation does not consider the accuracy, in meters, of the prediction, only the trend. This means there could be a significant difference at the verification time between Zi of the radiosonde and Zi of the model or persistence, yet the trend could have been correctly predicted.

Considering all 28 cases under examination, the model predicted the trend correctly 60.7% of the time, whereas, persistence predicted the trend correctly in 57.1% of the cases.

The 28 cases were further subdivided into clear or cloudy sky conditions, existing at the onset of the examination period, to determine if the initial sky conditions had any affect on the trend predictions. There were 18 cloudy and 10 clear sky cases. Both the model and persistence predicted the duct trend correctly in 70% (7 of 10) of the clear sky cases. Persistence was correct in 50% (9 of 18) of the cloudy sky cases, however, the model was correct in 66.7% (12 of 18) of the cloudy sky cases. This data is shown in Table I.

TABLE I

Duct Trend Prediction

Number	Type	Model	%Correct	Persistence	%Correct
28	All	17 correct	60.7	16 correct	57.1
18	Cloudy	12 correct	66.7	9 correct	50.0
10	Clear	7 correct	70.0	7 correct	70.0

Another consideration was, how accurately does the model and persistence predict sky conditions (cloudy, clear) at the end of the 24 hour period? Table II shows that persistence predicted the correct sky conditions in 60.7% of the cases (17 of 28) compared to 46.4% (13 of 28) for the model.

TABLE II

Prediction of Sky Conditions

Number	Model	% Correct	Persistence	% Correct
28	13 correct	46.4	17 correct	60.7

2. Inversion Height (Zi) Prediction

Table III is a complete listing of the raw data used in the analysis. This table gives the Date, Case Number, number of hours since the initial radiosonde sounding, the radisonde inversion height, MABL model prediction of Zi, and persistence prediction of Zi.

TABLE III

Complete Data Listing for Zi

Date	Case#	Hours Since Initial	Radiosonde	Model	Persistence
25 Sep. 1976	2	12	1448	1559	1488
		25	1365	1497	1448
26 Sep. 1976	3	11	1294	1723	1365
		24	114	2085	1294
03 Oct. 1976	7	9	307	224	475
		21	154	84	307
		24	180	68	154
10 Oct. 1976	10	11.5	193	193	260
		24	336	142	193
11 Oct. 1976	11	11.5	237	556	336
		22.5	485	772	237
20 July 1977	12	16.5	198	747	510
		24	305	871	198
21 July 1977	13	16.5	190	485	305
		23	546	539	190
		24	339	574	546
11 May 1978	17	5.5	455	471	425
		11	401	493	455
		24	232	498	401
14 May 1978	20	12.5	178	503	337
		15.5	1183	582	178
		24	1163	780	1183
19 May 1978	21	12.5	240	321	217
		23.5	351	510	240
20 May 1978	22	11.5	465	545	351
		24	628	817	465
21 May 1978	23	15.5	685	895	628
		24	688	1062	685

TABLE III (cont.)

Date	Case#	Hours Since Initial	Radiosonde	Model	Persistence
22 May 1978	24	4	922	732	686
		10.5	733	806	922
		23.5	1515	955	733
21 Aug. 1978	25	14.5	382	166	475
		23.5	384	112	382
22 Aug. 1978	26	12	409	424	384
		24.5	350	461	409
23 Aug. 1978	27	12	318	330	350
		23.5	362	345	318
24 Aug. 1978	28	12.5	299	500	362
		24	241	619	299
25 Aug. 1978	29	12	197	235	241
		24.5	166	232	197
08 Aug. 1978	32	12.5	319	314	290
		19	364	336	319
		24.5	334	350	364
09 Aug. 1978	33	6	338	288	334
		13	343	254	338
		18.5	445	234	343
		24	454	222	445
10 Aug. 1978	34	6	326	242	314
		14	233	231	326
		24	322	225	233
11 Aug. 1978	35	12	565	366	322
		24	983	435	565
12 Aug. 1978	36	12	292	1090	945
		24	857	1436	292
13 Aug. 1978	37	12	313	965	857
		19	216	1097	313
		24.5	135	1233	216

TABLE III (cont.)

Date	Case#	Hours Since Initial	Radiosonde	Model	Persistence
15 Aug. 1979	39	6	792	254	328
		12	512	299	792
		24	767	348	512
23 May 1980	42	7	482	632	544
		15	292	739	482
		23.5	506	857	292
24 May 1980	43	7.5	382	256	225
		19	490	255	382
		23	527	255	490
25 May 1980	44	9.5	984	563	527
		24.5	254	807	984

In order to perform statistical analyses on the predictive accuracy of the MABL model and persistence, the Hewlett-Packard HP-85 was used to obtain necessary statistical values. The program "DISTR" was used to assemble input data sets in ascending order and to calculate the mean, standard deviation, and the range of the data set. The program "BIN" was used to divide each data set into bins of equal width to form a histogram of the data set. "TPLOT" was then used to plot each data set. The program "PLOTP" was used to enter data pairs, then "TPLOT" was used to make a scatter plot of the entered points. These programs are listed in Appendix A.

In an effort to obtain more useful information, five particular situations were evaluated. The five

categories chosen were: 1) all 69 data points, 2) 67 data points with the high and low values from category 1 excluded, 3) the time when the verification was taken during the 24 hour examination period, 4) the season of the year when the verificaton was taken, and 5) the initial sky conditions. Within categories 3, 4, and 5 there were 4, 3, and 2 classes, respectively. Classes within categories are mutually exclusive. Categories 1 and 2 had only one class each. In all, there were eleven classes evaluated, each class containing two data sets, one for model data and one for persistence data. The 5 categories and 11 associated classes are described in Table IV.

The Delta M and Delta P values for each data set are listed in Appendix B, in the output format of the HP-65 "DISTR" program. Delta M and Delta P were calculated by subtracting the model/persistence prediction from the radiosonde value at that time. The histograms of the prediction errors are in Appendix C.

Table V is a compilation of the data set filenames, the number of data points, N, in the set, and the mean and standard deviation of the set in meters.

Ideally, the desired error between the radiosonde sounding and the prediction value (model or persistence) is zero. So, the desired mean of each data set is zero. The desired standard deviation, of the

prediction error, is, ideally, plus or minus 50 meters (plus or minus 100 meters will also be examined). Any inversion heights which cannot be predicted within plus or minus 50 meters is of little or no value to a tactician. This predicted value is critical because frequencies which are trapped within a duct are a function of duct thickness (Kerr 1951) and the transmitting/receiving antenna must be located within the duct for maximum exploitation. Therefore, the standard deviation is an important statistic in that it is a measure of the precision of the prediction. In other words, it reveals how much fluctuation, about the mean, occurs for a given data set. The larger the standard deviation, the less precise the prediction.

The given mean and standard deviations do not clearly reveal the predictive worth of either the model or persistence. In order to make more concise statements about the two predictive methods, it will be useful to perform hypotheses tests utilizing this data and a level of significance, α, of 0.01.

a. Hypothesis Concerning One Mean

Hypothesis testing is done to determine whether or not a given statement concerning a data set can be accepted with a probability α of risking a Type I error [Ref. 3: p. 195]. This is referred to as the null hypothesis, Ho.

TABLE IV

Category/Class Description

Category Number	Class Number	Description
1	1	All 69 data points used
2	2	67 data points used. The high and low values from data set 1 were excluded.
3	3	Radiosonde soundings which occurred 4 to 10.99 hours after initial launch
3	4	Radiosonde soundings which occurred 11 to 13 hours after initial launch
3	5	Radiosonde soundings which occurred 17.71 to 22.99 hours after initial launch
3	6	Radiosonde soundings which occurred 23 to 25 hours after initial launch
4	7	Radiosonde soundings taken during March, April, and May
4	8	Radiosonde soundings taken during June, July, and August
4	9	Radiosonde soundings taken during September, October, and November
5	10	Sky conditions clear
5	11	Sky conditions cloudy

TABLE V

Mean and Standard Deviation

Data Set Filename	N	Mean	Standard Deviation
Model1	69	80.812	412.026
Persist1	69	-4.565	279.752
Model2	67	62.806	335.426
Persist2	67	-11.881	217.242
Model3	10	-121.100	198.291
Persist3	10	-57.600	183.947
Model4	18	149.056	261.882
Persist4	18	93.278	279.622
Model5	12	158.917	333.733
Persist5	12	40.917	148.878
Model6	27	30.704	383.166
Persist6	27	-88.519	223.995
Model7	22	56.864	287.282
Persist7	22	-48.591	203.037
Model8	35	61.086	390.058
Persist8	35	0.000	241.952
Model9	10	81.900	198.226
Persist9	10	27.300	124.982
Model10	25	22.920	450.580
Persist10	25	-38.720	335.522
Model11	44	140.023	372.337
Persist11	44	7.870	248.600

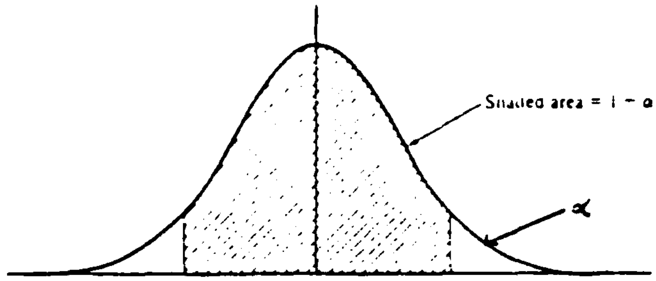


Figure 4. Type I Error

Given the distribution in Figure 4, a Type I error would be the probability α of rejecting the hypothesis when it is true.

The null hypothesis chosen was, $H_o: \mu = \mu_o$, which in words states, is the mean of Delta M/Delta P equal to μ_o, a specified value for the desired mean. Since Delta M and Delta P are the errors associated with the difference between the model or persistence prediction and the radiosonde value and the desired error to be zero, then μ_o was chosen to equal zero. Another way of stating this would be: Can it be said with reasonable confidence (99%) that the mean of the error for each predictive method be assumed to be zero?

In order to carry out this test, the Student's t-test was used. The assumptions required for this test are that the actual standard deviation, σ, be unknown and that the sample comes from a normal population. The t statistic is,

$$t = \frac{\overline{x} - \mu o}{S/\sqrt{n}}$$

where $\overline{x}$ equals the mean of the sample, $\mu o = 0.0$, S is the sample standard deviation, and n is the number of data points in the set. This calculated value of t was compared to a value obtained from a t-statistic table. This value was obtained by entering the table with the number of degrees of freedom, in this case n-1, and $\alpha/2 = 0.005$ because this is a two-tail test. If the absolute value of t-calculated is greater than t-table than the hypothesis is accepted. Figure 5 shows the acceptance/rejection regions for a two-tail test [Ref. 3: pp. 211-214].

The results of the hypothesis test, Ho: $\mu = \mu o$ for each data set are shown in Table VI.

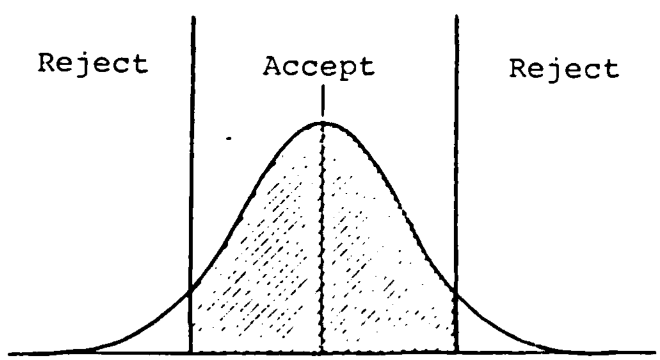


Figure 5. Acceptance/Rejection Regions

TABLE VI

Ho: $\mu = \mu_o = 0.0$

Filename	n	t-calc	t-table	Accept/Reject
Model1	69	1.640	2.576	Accept
Persist1	69	-0.136	-2.576	Accept
Model2	67	1.533	2.576	Accept
Persist2	67	-0.449	-2.576	Accept
Model3	10	-1.930	-3.250	Accept
Persist3	10	-0.990	-3.250	Accept
Model4	18	2.415	2.898	Accept
Persist4	18	1.888	2.898	Accept
Model5	12	1.652	3.106	Accept
Persist5	12	0.952	3.106	Accept
Model6	27	0.416	2.779	Accept
Persist6	27	-2.253	-2.779	Accept
Model7	22	0.928	2.831	Accept
Persist7	22	-1.123	-2.831	Accept
Model8	35	0.927	2.576	Accept
Persist8	35	0.000	2.576	Accept
Model9	10	1.307	3.250	Accept
Persist9	10	0.691	3.250	Accept
Model10	25	0.254	2.797	Accept
Persist10	25	-0.577	-2.797	Accept
Model11	44	2.490	2.576	Accept
Persist11	44	0.210	2.576	Accept

b. Hypothesis Concerning One Variance

The null hypothesis considered in this section will be to determine if the population standard deviation is equal to a specified constant (Ho: $\sigma = \sigma_o$). This test is conducted by calculating the Chi-Square statistic,

$$\chi^2 = \frac{(n-1)S^2}{\sigma_o^2}$$

where n is the number of data points in the sample population, S^2 is the variance of the sample, and σ_o^2 is the specified (desired) variance (variance is the square of the standard deviation). The Chi-Square calculated value is then compared to a Chi-Square value obtained from a table in Ref. 3, using n-1 degrees of freedom and $\alpha = 0.01$. If the calculated value is less than $\chi_{\alpha/2}$ or greater than $\chi_{1-\alpha/2}$, the null hypothesis is accepted. The desired standard deviation was chosen to be σ_o = 50 meters, however, σ_o = 100 meters was also tested. The results of these tests are given in Table VII [Ref. 3: pp. 233-235].

c. Hypothesis Concerning Two Means

In order to determine if there is a significant difference between the two means, the model and persistence, the null hypothesis, Ho: $\mu_m = \mu_p$ must be examined. Along with the assumption of normality, a statement must be made about the variances of the two data sets. Namely, can it be assumed that the variances σ_m^2

TABLE VII

$H_o: \sigma = \sigma_o$

σ_o = 50 and 100 meters

Filename	S^2	χ^2-calculated 50	χ^2-calculated 100	χ^2-table	Accept/Reject 50	Accept/Reject 100
Model1	1.7×10^5	4570	1140	102.3	Reject	Reject
Persist1	7.9×10^4	2130	532	102.3	Reject	Reject
Model2	1.1×10^5	2980	746	99.5	Reject	Reject
Persist2	4.7×10^4	1250	312	99.5	Reject	Reject
Model3	3.9×10^4	141	35	23.6	Reject	Reject
Persist3	3.4×10^4	122	30	23.6	Reject	Reject
Model4	6.9×10^4	466	117	35.7	Reject	Reject
Persist4	4.4×10^4	299	74	35.7	Reject	Reject
Model5	1.1×10^5	488	122	26.8	Reject	Reject
Persist5	2.2×10^4	97	24	26.8	Reject	Accept
Model6	1.5×10^5	1530	382	48.3	Reject	Reject
Persist6	5.0×10^4	522	131	48.3	Reject	Reject
Model7	8.3×10^4	693	173	41.4	Reject	Reject
Persist7	4.1×10^4	346	86	41.4	Reject	Reject
Model8	1.5×10^5	2070	517	56.1	Reject	Reject
Persist8	5.9×10^4	796	199	56.1	Reject	Reject
Model9	3.9×10^4	141	35	23.6	Reject	Reject
Persist9	1.6×10^4	56	14	23.6	Reject	Accept
Model10	2.0×10^5	1950	487	45.6	Reject	Reject

TABLE VII (cont.)

Filename	S^2	χ^2-calculated 50	χ^2-calculated 100	χ^2-table	Accept/Reject 50	Accept/Reject 100
Persist10	1.1×10^5	1080	271	45.6	Reject	Reject
Model11	1.4×10^5	2390	598	71.0	Reject	Reject
Persist11	6.2×10^4	1060	266	71.0	Reject	Reject

and σ_p^2 are equal? The null hypothesis Ho: $\sigma_m^2 = \sigma_p^2$ must be completed to answer this. If it can be said that they are equal, (i.e. accept the hypothesis), then a two-sample t test can be used to test the means. If the hypothesis that the variances are equal is rejected, then a paired-sample t test must be used to test the means.

In order to perform the hypothesis test, an F-statistic was calculated by,

$$F = \frac{S_m^2}{S_p^2}$$

where S_m^2 is the variance of the model data and S_p^2 is the variance of the persistence data. Using $\alpha = 0.01$, if F-calc was less than F-table then the hypothesis, Ho: $\sigma_m^2 = \sigma_p^2$ must be accepted. The results are shown in Table VIII.

TABLE VIII

Ho: $\sigma_m^2 = \sigma_p^2$

Data Set #	F-calculated	F-table	Accept/Reject
1	2.15	1.66	Reject
2	2.39	1.66	Reject
3	1.16	5.35	Accept
4	1.56	3.52	Accept
5	5.00	4.54	Reject
6	2.93	2.52	Reject
7	2.00	2.88	Accept
8	2.60	2.30	Reject
9	2.52	5.35	Accept
10	1.90	2.66	Accept
11	2.25	2.05	Reject

The five data sets accepted as having equal variances were then tested with the hypothesis, Ho: $\mu_T - \mu_P = 0.0$. The two-sample test was used where, after reduction of the general formula [Ref. 3: p. 219].

$$t = \frac{(\mu_m - \mu_p)\ n(n-1)}{\sqrt{(n-1)[S_m^2 + S_p^2]}}$$

with $\alpha = 0.01$ and the degrees of freedom being 2 * (n-1). The results are given in Table IX.

TABLE IX

Ho: $\mu_T - \mu_P = 0.0$

Data Set#	$S_T^2 + S_P^2$	t-calc	t-table	Accept/Reject
3	7.3×10^4	-0.71	-2.92	Accept
4	1.1×10^5	0.69	2.58	Accept
7	1.2×10^5	1.37	2.58	Accept
9	5.5×10^4	0.70	2.92	Accept
10	3.2×10^5	0.02	2.58	Accept

The six data sets rejected for not being able to make the assumption that the variances are equal had their means tested for equality using the paired-sample t test. In order to conduct this test, a data set containing the values, Delta M − Delta P, was compiled and a mean and

standard deviation for each data set was calculated using "DISTR". The desired mean, μ_o, of each data set is once again zero. The t statistic was calculated for each of the 6 sets as in Section A. The six paired data sets are listed in Appendix D and the results of the hypothesis, Ho: $\mu = \mu_o = 0.0$, are listed in Table X.

TABLE X

Ho: $\mu = \mu_o = 0.0$

Data Set #	t-calculated	t-table	Accept/Reject
1	2.91	2.59	Reject
2	3.01	2.58	Reject
5	1.65	3.26	Accept
6	2.59	2.76	Accept
8	1.64	2.58	Accept
11	3.79	2.58	Reject

d. Prediction Error vs. Verification Time

Figures 6 and 7 are plots of the Prediction Error vs. Verification Time. With zero being the desired error, it is clear that as the model progresses further into the 24 hour prediction period, that the prediction error increases significantly. The standard deviation varies from 198.091 meters to 393.166 meters (from Table V).

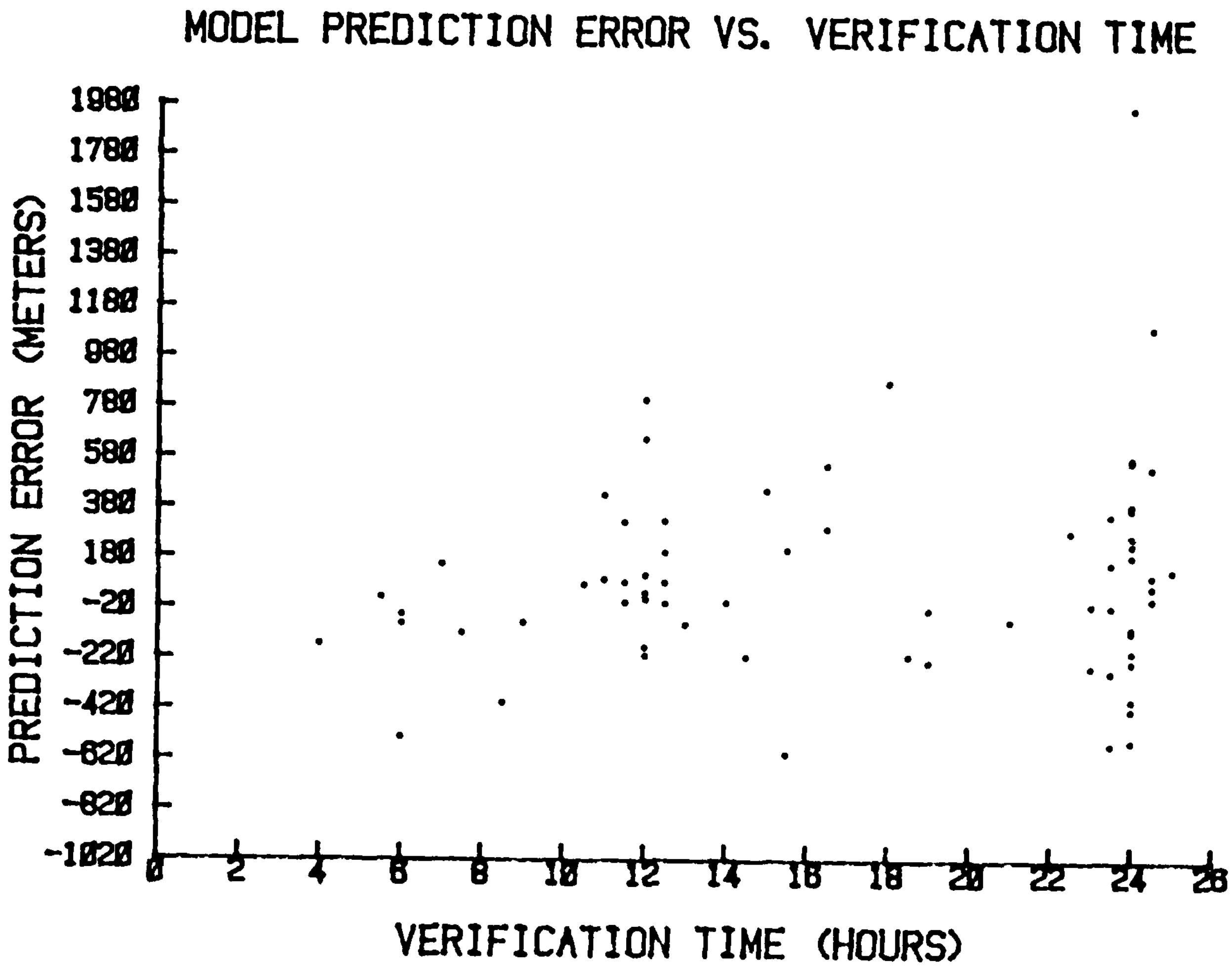


Figure 6. Model Prediction Error vs. Verification Time

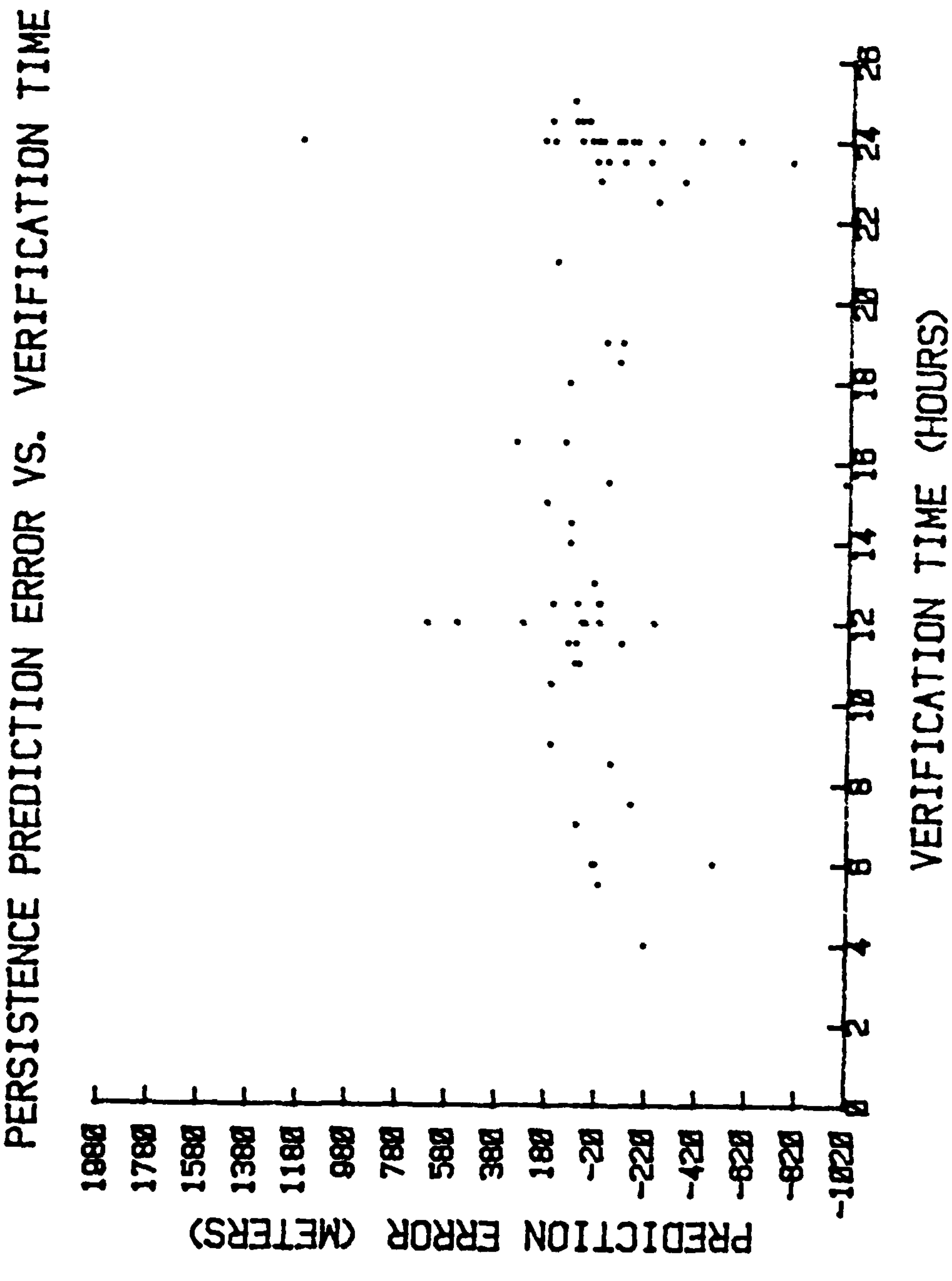


Figure 7. Persistence Prediction Error vs. Verification Time

The Persistence Prediction Error plot reveals much less scattering of the data points, while there is no obvious trend to the prediction error.

e. Prediction Error vs. Month of Observation

Figures 8 and 9 are plots of the 69 data points relative to the month in which they were taken. The X-axis of these two figures are labeled by numbers, where 1 corresponds to January through 12 which is December. It is obvious that there is much more scatter associated with the model's prediction error during the summer months than at other times.

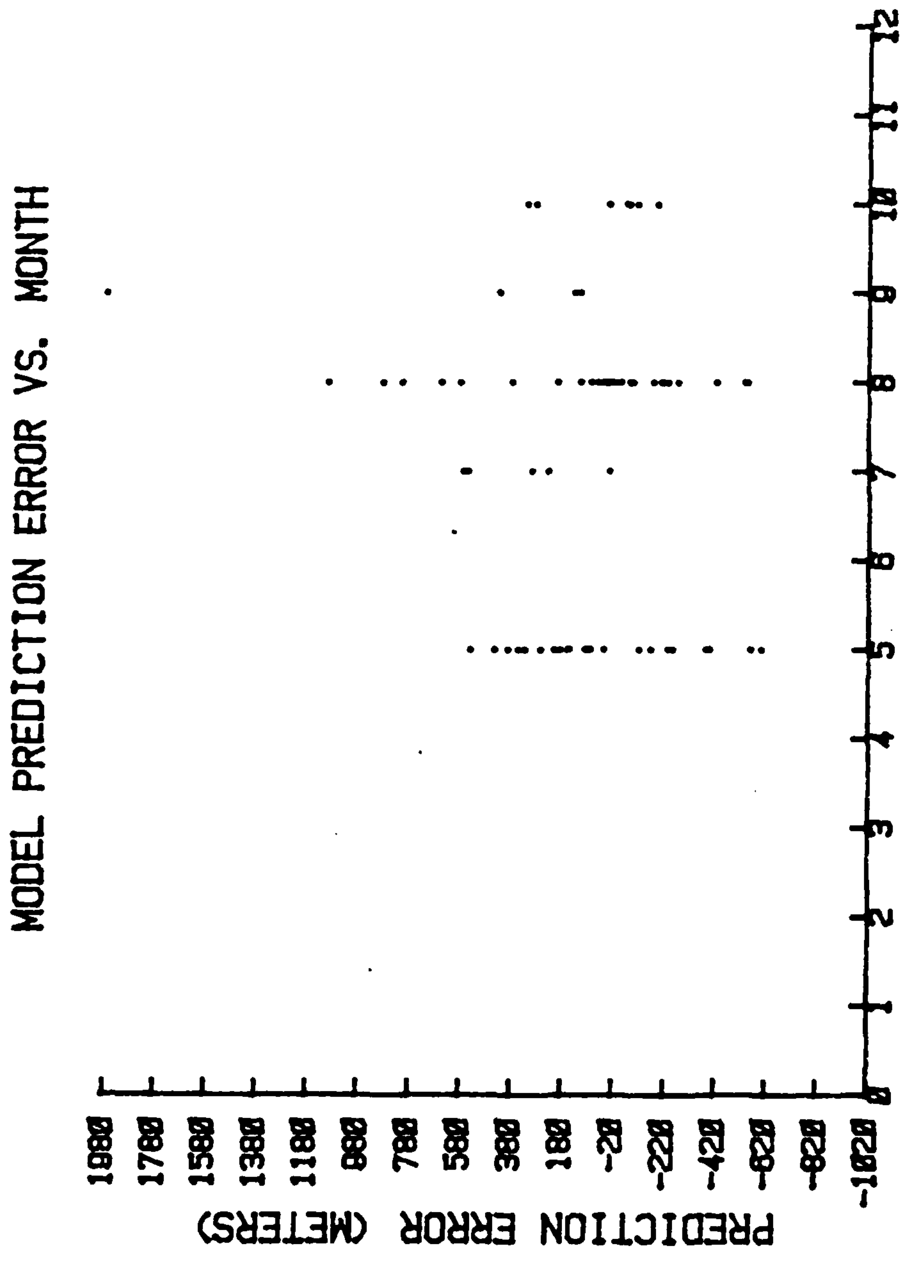


Figure 8. Model Prediction Error vs. Month of Observation

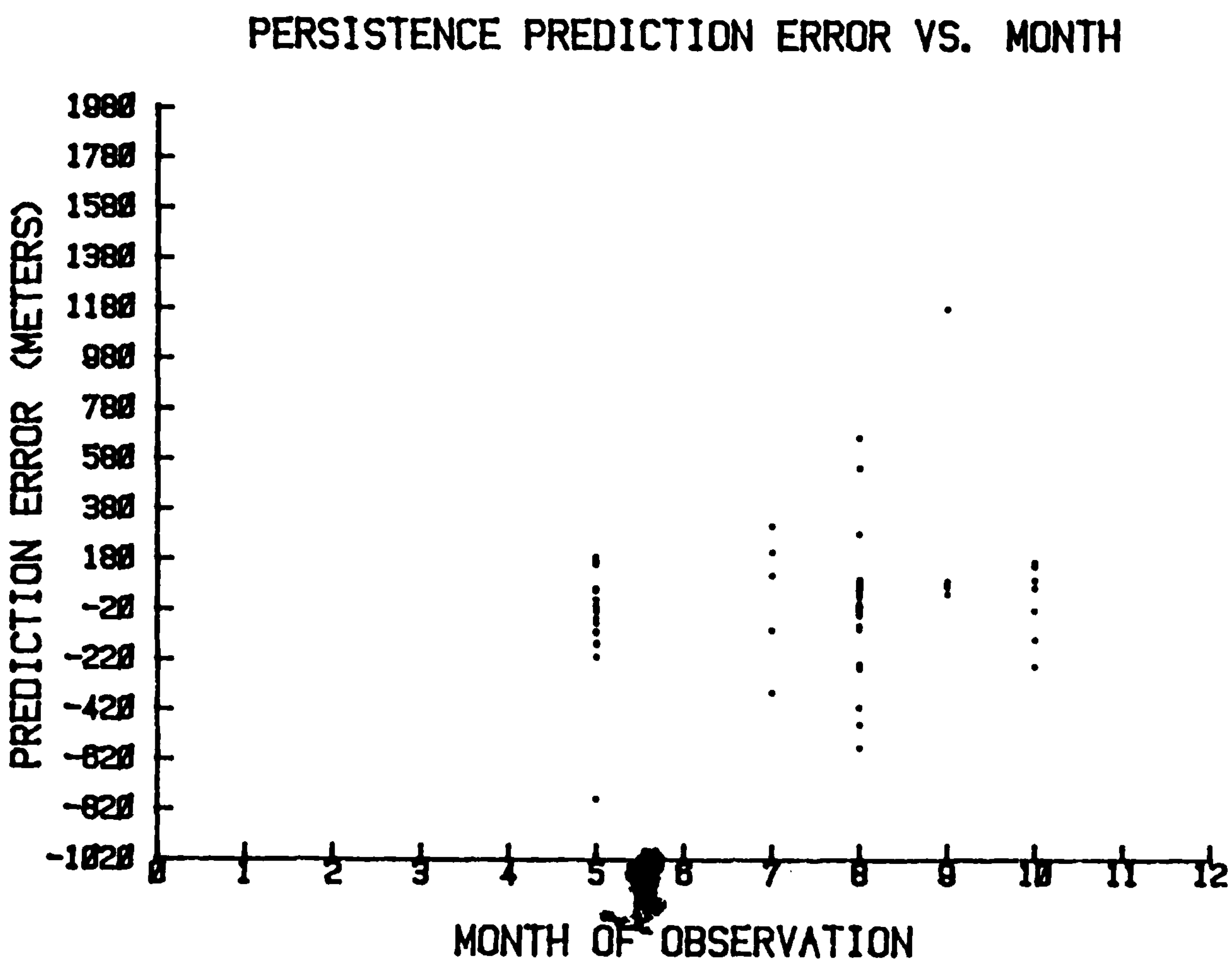


Figure 9. Persistence Prediction Error vs. Month of Observation

V. CONCLUSIONS

A. DUCT TREND PREDICTION

From a statistical viewpoint there is no significant difference between the MABL model and persistence in predicting the duct trend or sky (clouds/no clouds) conditions. There are some differences in their correct prediction percentages, however, not enough to choose one method over the other. The results clearly indicate that, given sky conditions are clear at the initial start time, the duct trend can be accurately predicted by either method. Cloud formation appears to cause problems in the model's predictive ability and should be further investigated.

B. HYPOTHESES TESTS

Although the hypothesis test of Section IIIa. showed that the mean of each data set had to be accepted as being equal to zero, this can prove to be misleading. This result should be easily expected considering the large standard deviations in the data. The hypothesis test which contains extremely important results, from the tacticians viewpoint, is the test of Section IIIb. Remembering, that standard deviation is a measure of the precision of the

prediction, it can be stated quite assuredly that the inversion height cannot be predicted accurately, either by the model or persistence, to the degree required for tactical employment. In all cases, the accuracy of persistence was better than the model, but still not good enough for tactical use.

The hypothesis tests concerning the equality of the means revealed that there is no significant difference between the populations. Once again, this can be misleading due to the large standard deviations encountered.

C. PREDICTION ERROR VS. VERIFICATION TIME

Figure 6 clearly indicates the model's predictive ability decreases significantly the further it progresses into the 24 hour period. Figure 7 shows much less scatter associated with the persistence predictions. These plots seem to indicate that the model was expecting/predicting a much greater change in Zi than actually occurred.

D. PREDICTION ERROR VS. MONTH OF OBSERVATION

Figure 8 indicates the model's predictive ability is significantly reduced during the summer months. There is much more scatter associated with the summer months than others. The month of observation had no discernible affect on persistence as seen in Figure 9.

E. SKY CONDITIONS

Initial sky conditions had no apparent affect on the model or persistence.

F. GENERAL CONCLUSIONS

The results appear to point toward a conclusion that the MABL model and persistence are not useable, from a tactical viewpoint. More testing and statistical work should be done before a judgement can be made about the model physics. The next chapter deals with approaches which should be taken in an effort to make a more valid evaluation of the MABL model.

VI. RECOMMENDATIONS

Proper experimental planning can give a reasonable assurance that the results of an experiment will provide clear-cut answers to questions under investigation.

The examination in this thesis made the major assumption that the radiosonde data was "perfect" and that any results would indicate the precision of the models' predictive ability. However, it is widely known, and accepted, that radiosonde data are not "perfect" because the radiosone is not sensitive enough to abrupt changes in atmospheric conditions as it ascends. In order to determine if the error contributed by the radiosonde is significant and if the radiosonde data differs significantly from an alternate method of collecting the same type of data, an Analysis of Variance (ANOVA) study should be done involving three separate comparisons. A complete discussion of this method can be found in Chapter 12 of Ref. 3. The mathematics of this method will not be discussed here, but suggested procedures for conducting the necessary data collection will be elaborated upon.

The three ANOVA comparisons recommended are delineated in the following subsections.

A. RADIOSONDE VS. RADIOSONDE

To determine if the data received by radiosondes is consistent, a test should be conducted in which two radiosondes are launched within minutes of each other at each observation time. Ensuring that both radiosondes are identically calibrated and launched from a weather deck where there will be little possiblilty of collision with other structures during ascent, the first radiosonde should be launched and then the second launched a few minutes later. Dual launches should be made at each measurement period. The number of dual launches made should be limited to between 5 and 12 because of cost and a large number of dual launches will not be necessary to check for consistency in data. It is imperative that the ANOVA tests be carried out even if by observation the data appears consistent. This data can then be used to evaluate the degree of consistency in received radiosonde data. Regardless whether the tests determine if the data from two different radiosondes is consistent or not consistent, further tests will be necessary.

B. REFRACTOMETER VS. REFRACTOMETER

The AN/AMH-3 (XAN-5) Airborne Microwave Refractometer (AMR) is currently used in some Navy aircraft to obtain the same type of information which radiosondes provide.

Simultaneous data should be collected by two aircraft to determine the degree of consistency in refractometer measurements. This test will require the same aircraft to carry two different refractometers or two aircraft each carrying an AMR and launched within minutes of each other and flying the same pattern. As a result of the ANOVA test of this data, if the consistency is good then the Refractometer can be used in a test comparing it's data to the radiosonde.

C. RADIOSONDE VS. REFRACTOMETER

In order to determine if there is any significant difference between radiosonde data and refractometer data, data should be collected within 30-60 minutes of each other. If there is significant difference in the data then careful consideration should be taken to determine which, if either, method provides the more accurate data.

Once these tests have been done and the statistical results determined, then much clearer statements can be made about the model's predictive ability because more will be known about the quality of the input data.

D. GENERAL RECOMMENDATIONS

The other parameters which are predicted by the model should undergo similar statistical analysis as that which has been done on the parameter Zi. This analysis is

necessary so that a clearer understanding of the model's predictive abilities is known.

Some caution and consideration should be given to the results of the three tests suggested above, because the results for any or all of the tests for one geographical location and/or time of year of the test may agree or disagree does not necessarily mean the results will or will not agree for another location or different time.

No attempt should be made to alter the MABL model until the ANOVA tests are done. A qualitative and quantitative assessment of the input data is imperative before a fair evaluation of the MABL model can be made.

APPENDIX A

HP-85 PROGRAMS

The programs used in this thesis are listed on the following pages. Each program can be used on an HP-85 by first starting the machine and placing a disk with the programs on it into the disk drive. Next type, MASS STORAGE IS ":D700", then hit the END LINE key, then type, LOAD "program name" and then the END LINE key. The END LINE key must be used after an entry. Once the program is loaded, hit the RUN key and the program will prompt for inputs.

The program "DISTR" will first prompt for a data filename. Upon entering the filename, the next prompt will be to enter the number of data points. The data can be entered in any order. Once the last point has been entered the program ranks the data in ascending order, computes the mean, standard deviation, maximum and minimum values of the data, and the range. It then prints the data plus the results of the computations.

The program "BIN" is used to divide the data into bins of equal width in order to make a histogram plot. The program prompts for the data filename, then the distribution filename. The data and distribution filenames

must differ. The next prompt is for the number of bins. This value is any integer value less than the number of data points. The number of bins chosen should be such that there are at least two data points per bin whenever possible.

Upon completion of the "BIN" program, "TPLOT" can be loaded for use in making a histogram plot. The first prompt is for the data filename, however, enter the distribution filename for which a plot is desired. A prompt for the title and subtitle of the plot are displayed next. If either or both of these are not required, hit the END LINE key and the next prompt will be displayed. The next entries are XMIN,XMAX,YMIN,YMAX. These are the maximum and minumum values for the horizontal and vertical axis, respectively. The four values should be entered on the same line separated by commas before keying END LINE. The next prompt is X AXIS LOG SCALE ENTER Y or N. Upon answering yes or no, the next prompt is XINTV,YINTV,XINTC,YINTC. These values are the x and y intervals for labeling of the x and y axis and the x and y axis intercepts. The x and y axis titles are requested next. Upon completing these entries, a plot is made on the screen. When the plot is done hit the CONTINUE key and the number 8 (for a hard copy) and it will plot on the plotter.

The "PLOTP" program should be used if x and y paired data is required to be plotted. The first prompt is for the number of paired data sets. The next query is for the data filename. The next prompt will be for the paired data sets. Enter the x coordinate first followed by a comma then the y coordinate followed by the END LINE key. Upon completion of entering the data sets, "TPLOT" can be used to make a scatter plot.

" D I S T R "

```
10 MASS STORAGE IS ":D700"
20 DISP "DATA FILENAME"
30 INPUT D$
40 DIM D(250)
50 DISP "NO. OF DATA POINTS"
60 INPUT D(0)
70 B=(D(0)+1) DIV 8+1
80 B=B*8
90 CREATE D$,16,B
100 PRINT "DATA FILENAME ";D$
110 FOR I=1 TO D(0)
120 DISP "DATA PT ";I
130 INPUT D(I)
140 NEXT I
150 FOR J=1 TO D(0)
160 M=10000
170 FOR I=J TO D(0)
180 IF D(I)<M THEN M=D(I) @ L=I
190 NEXT I
200 G=D(J) @ D(J)=M @ D(L)=G
210 NEXT J
220 S=0
230 S2=0
240 FOR I=1 TO D(0)
250 S=S+D(I)
260 PRINT D(I)
270 S2=S2+D(I)^2
280 NEXT I
290 X=S/D(0)
300 PRINT "MEAN VALUE = ";X
310 Y=SQR(S2/D(0)-X^2)
320 PRINT "SDEV= ";Y
330 PRINT "MIN VALUE = ";D(1)
340 PRINT "MAX VALUE = ";D(D(0))

350 PRINT "RANGE = ";D(D(0))-D(1
)
360 ASSIGN# 1 TO D$
370 FOR I=0 TO D(0)
380 PRINT# 1 ; D(I)
390 NEXT I
400 ASSIGN# 1 TO *
410 END
```

"BIN"

```
10 DIM D(250),F(250)
20 DISP "DATA FILENAME"
30 INPUT D$
40 DISP "DISTRIBUTION FILENAME"
50 INPUT F$
60 PRINT "DISTRIBUTION FILENAME
",F$
70 DISP "NO OF BINS"
80 INPUT G
90 ASSIGN# 1 TO D$
100 READ# 1 ; D(0)
110 FOR I=1 TO D(0)
120 READ# 1 ; D(I)
130 NEXT I
140 B=(D(0)+1) DIV 8+1
150 B=B*8
160 CREATE F$,16,B
170 S=(D(D(0))-D(1))/G
180 F(0)=G
190 J=1
200 L=D(1)
210 PRINT "BIN PT, NO., LIMIT, D
: PT."
220 FOR I=1 TO 2*G STEP 2
230 L=L+S @ F(I)=L-S/2 @ F(I+1)=
0
240 IF J>D(0) THEN 300
250 IF D(J)>L THEN 290
260 F(I+1)=F(I+1)+1
270 PRINT F(I);F(I+1);L;J
280 J=J+1 @ GOTO 240
290 NEXT I
300 ASSIGN# 1 TO F$
310 FOR I=0 TO 2*G
320 PRINT# 1 ; F(I)
330 NEXT I
340 ASSIGN# 1 TO *
350 END
```

" T P L O T "

```
10 REAL K1(8) ! LOG VALUES
20 DIM D(2500) ! THE DATA
30 DIM A$[50],A1$[50],B$[25],C$[
25]
40 GCLEAR
50 DISP "ANSWER PROMPTS WITH 'Y'
OR 'N'"
60 P=0
70 PLOTTER IS 1
80 GCLEAR
90 IF P=8 THEN 190 ! HARD COPY
100 IF P=1 THEN 190 ! REDRAW
110 IF P=2 THEN 160 ! CHG TITLES

120 IF P=3 THEN 180 ! CHG X/Y AX
ES
130 GOSUB 670 ! READ DATA
140 IF P=4 THEN 200 ! MORE DATA
SAME PLOT
150 IF P=5 THEN 200 ! MULTIPLOT
160 GOSUB 380 ! TITLES
170 IF P=2 THEN 190 ! CHG TITLES

180 GOSUB 440 ! X/Y AXES
190 GOSUB 770 ! DRAW AXES
200 GOSUB 1430 ! PLOT DATA
210 PAUSE
220 ! SELECT PLOT
230 DISP "CHOOSE PARAMETER"
240 DISP "            1-REDRAW"
250 DISP "            2-CHG TITLES"
260 DISP "            3-CHG X/Y AXES"
270 DISP "            4-MORE DATA SAME
              PLOT"
280 DISP "            5-MULTIPLOT"
290 DISP "            6-NEW PLOT"
300 DISP "            7-END PLOTTING"
310 DISP "            8-HARD COPY"
320 INPUT P
330 IF P=4 THEN 90
340 IF P=8 THEN PLOTTER IS 705 @
 GOTO 80
350 IF P=1 THEN PLOTTER IS 705 @
 GOTO 80
360 IF P=7 THEN 1680 ! END
370 GOTO 70
380 ! TITLES
390 DISP "TITLE"
400 INPUT A$
410 DISP "SUBTITLE"
420 INPUT A1$
430 RETURN
440 ! X/Y AXES
450 DISP "INPUT XMIN,XMAX,YMIN,Y
MAX"
460 INPUT X1,X2,Y1,Y2
470 DISP "X AXIS LOG SCALE?"
480 DISP "ENTER Y OR N"
490 INPUT Q0$
500 IF Q0$<>"Y" THEN 560
510 X3=0
520 X4=X1
530 DISP "YINTV,YINTC"
540 INPUT Y3,Y4
550 GOTO 660
560 DISP "INPUT XINTV,YINTV,XINT
C,YINTC"
570 INPUT X3,Y3,X4,Y4
580 IF P=0 THEN 620
590 DISP "CHG AXIS LABELS? Y/N"
600 INPUT Q1$
610 IF Q1$="N" THEN 660
620 DISP "XAXIS TITLE"
630 INPUT B$
640 DISP "YAXIS TITLE"
650 INPUT C$
660 RETURN
670 ! READ DATA
680 DISP "DATA FILENAME"
690 INPUT F$
700 ASSIGN# 1 TO F$
710 READ# 1 , N9
720 N9=2*N9
730 FOR I=1 TO N9
```

" T P L O T " (cont.)

```
740 READ# 1 ; D(I)
750 NEXT I
760 RETURN
770 ! DRAW AXES
780 LOCATE 30,110,32,89
790 CSIZE 3
800 ! DRAW LINEAR?
810 IF Q0$<>"Y" THEN GOSUB 1010
820 ! OR DRAW SEMILOG
830 IF Q0$="Y" THEN GOSUB 1160
840 ! PUT LABELS
850 PLOT (X1+X2)/2,Y2+3*(Y2-Y1)/
26,-2
860 LORG 6
870 CSIZE 4
880 LABEL A$
890 LABEL A1$
900 PLOT (X1+X2)/2,Y1-(Y2-Y1)/8,
-2
910 LORG 4
920 LABEL B$
930 DEG
940 LDIR 90
950 LORG 6
960 LORG 5
970 PLOT X1-(X2-X1)/8,(Y1+Y2)/2,
-2
980 LABEL C$
990 LDIR 0
1000 RETURN
1010 ! DRAW LINEAR AXIES
1020 SCALE X1,X2,Y1,Y2
1030 AXES X3,Y3,X4,Y4
1040 LORG 5
1050 FOR X=X1 TO X2 STEP X3
1060 PLOT X,Y1-(Y2-Y1)/55
1070 LABEL USING "K" ; X
1080 NEXT X
1090 LORG 8
1100 FOR Y=Y1 TO Y2 STEP Y3
1110 PLOT X1-(X2-X1)/40,Y
1120 LABEL USING "K" ; Y
1130 NEXT Y
1140 RETURN
1150 ! DRAW LOGX-AXIS
1160 LORG 6
1170 IF L$="SET" THEN 1210
1180 L$="SET"
1190 X1=LGT(X1)
1200 X2=LGT(X2)
1210 FOR I=0 TO 8
1220 K1(I)=LGT(I+2)
1230 NEXT I
1240 SCALE X1,X2,Y1,Y2
1250 MOVE X1,Y1
1260 DRAW X2,Y1
1270 FOR I=X1 TO X2
1280 MOVE I,Y1-(Y2-Y1)/55
1290 LABEL USING "K" ; 10^I
1300 FOR J=0 TO 8
1310 K2=K1(J)+I
1320 MOVE K2,Y1
1330 DRAW K2,Y1+(Y2-Y1)/100
1340 NEXT J
1350 NEXT I
1360 YAXIS X1,Y3
1370 LORG 8
1380 FOR Y=Y1 TO Y2 STEP Y3
1390 PLOT X1-(X2-X1)/40,Y
1400 LABEL USING "K" ; Y
1410 NEXT Y
1420 RETURN
1430 ! PLOT DATA
1440 DISP "LINETYPE ?"
1450 DISP "  1 SOLID"
1460 DISP "  2 END PT ONLY"
1470 DISP "  3 DOTS"
1480 DISP "  4 SDASH"
1490 DISP "  5 LDASH"
1500 DISP "  6 DASH DOT"
1510 DISP "  7 LDASH SDASH"
1520 DISP "  8 LDASH SDASH SDASH
"
1530 INPUT L
```

" T P L O T " (cont.)

```
1540 LINETYPE L
1550 IF Q0$<>"Y" THEN 1580
1560 MOVE LGT(D(1)),D(2)
1570 GOTO 1590
1580 MOVE D(1),D(2)
1590 FOR I=1 TO N9 STEP 2
1600 IF Q0$<>"Y" THEN 1630
1610 PLOT LGT(D(I)),D(I+1)
1620 GOTO 1640
1630 PLOT D(I),D(I+1)
1640 NEXT I
1650 PENUP
1660 PENUP
1670 RETURN
1680 STOP
1690 END
```

"PLOTP"

```
10 DISP "NO. OF POINTS"
20 INPUT N
30 DIM D(200)
40 DISP "DATA FILENAME"
50 INPUT D$
60 B=N DIV 8+1
70 B=B*8
80 CREATE D$,16,B
90 D(0)=N
100 FOR I=1 TO 2*N STEP 2
110 DISP "INPUT X,Y"
120 INPUT D(I),D(I+1)
130 NEXT I
140 ASSIGN# 1 TO D$
150 FOR I=0 TO 2*N
160 PRINT# 1 ; D(I)
170 NEXT I
180 ASSIGN# 1 TO *
190 END
```

APPENDIX B

DELTA M/DELTA P VALUES

The Delta M and Delta P values for each data set are listed on the following pages in the output format of the HP-85 "DISTR" program. The Delta M values were obtained by subtracting the radiosonde value for Zi from the value predicted by the model at that time. The Delta P values were obtained by subtracting the current radiosonde value from the previous value.

DATA FILENAME MODEL1

-603	-579	-560
-548	-538	-422
-401	-323	-272
-252	-234	-234
-214	-211	-211
-194	-179	-170
-124	-112	-97
-89	-84	-83
-70	-50	-28
-15	-7	-5
-2	0	12
15	16	16
38	66	73
80	81	92
111	111	132
150	159	189
201	210	235
266	285	295
321	325	351
378	394	429
446	543	549
566	652	810
981	1098	1971

MEAN VALUE = 80.812
SDEV = 410.026
MIN VALUE = -603
MAX VALUE = 1971
RANGE = 2574

DATA FILFNAME PERSIST1

-1205	-762	-577
-484	-356	-257
-248	-243	-214
-214	-163	-155
-143	-114	-111
-110	-107	-102
-89	-76	-57
-48	-45	-42
-32	-30	-29
-26	-25	-23
-17	-12	-9
-5	-4	-3
-2	20	32
33	40	44
54	58	59
61	62	67
71	81	92
93	93	97
99	115	153
159	168	169
169	177	190
207	282	312
544	665	1180

MEAN VALUE = -4.565
SDEV = 279.752
MIN VALUE = -1205
MAX VALUE = 1180

DATA FILENAME MODEL2

-579	-560	-548
-539	-422	-401
-383	-272	-252
-234	-234	-214
-211	-211	-194
-179	-170	-124
-112	-97	-89
-84	-83	-70
-50	-28	-15
-7	-5	-2
0	12	15
16	16	38
66	73	80
81	92	111
111	132	150
159	189	201
210	235	266
285	295	321
325	351	379
394	429	446
543	549	566
652	810	881
1098		

MEAN VALUE = 62.80
SDEV = 335.426
MIN VALUE = -579
MAX VALUE = 1098
RANGE = 1677

DATA FILENAME PERSIST2

-782	-577	-484
-415	-356	-257
-248	-243	-214
-214	-163	-155
-143	-114	-111
-110	-107	-102
-89	-76	-57
-45	-42	-30
-29	-26	-25
-23	-17	-12
-9	-5	-4
-3	-2	20
30	32	33
42	44	54
58	59	61
62	67	71
81	92	93
93	97	99
115	153	159
168	169	169
177	190	207
282	312	544
665		

MEAN VALUE = -11.881
SDEV = 217.242
MIN VALUE = -782
MAX VALUE = 665
RANGE = 1447

DATA FILENAME MODEL3

```
-538
-401
-170
-124
 -84
 -83
 -50
  16
  73
 150

MEAN VALUE = -121.1
SDEV = 198.091
MIN VALUE = -538
MAX VALUE = 150
RANGE = 688
```

DATA FILENAME PERSIST3

```
-484
-214
-155
 -75
 -30
 -12
  -4
  62
 168
 169

MEAN VALUE = -57.6
SDEV = 183.947
MIN VALUE = -484
MAX VALUE = 169
RANGE = 653
```

DATA FILENAME MODEL4

```
-211
-179
 -89
  -5
   0
  12
  15
  38
  80
  81
  92
 111
 201
 321
 325
 429
 652
 810
```

MEAN VALUE = 149.056
SDEV = 261.880
MIN VALUE = -211
MAX VALUE = 810
RANGE = 1021

DATA FILENAME PERSIST4

-243
-114
-29
-25
-23
-5
32
40
44
54
61
67
71
99
159
282
544
665

MEAN VALUE = 93.278
STDEV = 209.622
MIN VALUE = -243
MAX VALUE = 665
RANGE = 908

DATA FILENAME MODEL5

```
-234
-214
-211
 -70
 -28
  -2
 210
 285
 295
 446
 549
 881
```

MEAN VALUE = 158.917
SDEV = 333.733
MIN VALUE = -234
MAX VALUE = 881
RANGE = 1115

DATA FILENAME PERSIST5

```
-248
-110
-102
 -57
 -45
  93
  93
  97
 115
 153
 190
 312
```

MEAN VALUE = 40.917
SDEV = 148.878
MIN VALUE = -248
MAX VALUE = 312
RANGE = 560

DATA FILENAME MODEL6

```
-579
-560
-548
-422
-383
-272
-252
-234
-194
-112
 -97
 -15
  -7
  16
  66
 111
 132
 159
 189
 235
 266
 351
 378
 394
 543
 566
1098
```

MEAN VALUE = 30.704
SDEV = 383.166
MIN VALUE = -579
MAX VALUE = 1098
RANGE = 1677

DATA FILENAME PERSIST6

-782
-577
-418
-356
-257
-214
-163
-143
-111
-107
-89
-42
-26
-17
-9
-3
-2
20
30
33
58
59
61
92
169
177
207

MEAN VALUE = -88.519
SDEV = 223.998
MIN VALUE = -782
MAX VALUE = 207
RANGE = 989

DATA FILENAME MODEL7

-560
-401
-383
-252
-234
-170
-124
16
73
80
81
92
150
159
189
210
266
325
351
394
446
543

MEAN VALUE = 56.864
SDEV = 287.282
MIN VALUE = -560
MAX VALUE = 543
RANGE = 1103

DATA FILENAME PERSIST7

```
-782
-214
-214
-163
-155
-114
-111
-110
 -76
 -57
 -30
 -23
 -17
  -3
  22
  54
  62
 159
 169
 169
 177
 190
```

```
MEAN VALUE = -48.591
SDEV = 203.037
MIN VALUE = -782
MAX VALUE = 190
RANGE = 972
```

DATA FILENAME MODELS

```
-579
-548
-539
-422
-272
-234
-214
-211
-211
-179
 -97
 -89
 -84
 -50
 -29
 -15
  -7
  -5
  -2
  12
  15
  16
  38
  56
 111
 201
 235
 295
 376
 549
 566
 652
 810
 881
1098
```

MEAN VALUE = 61.086
SDEV = 390.058
MIN VALUE = -579
MAX VALUE = 1098
RANGE = 1677

DATA FILENAME PERSISTE

```
-577
-484
-418
-356
-257
-243
-107
-102
 -89
 -45
 -42
 -29
 -25
 -12
  -9
  -5
  -4
  -2
  30
  32
  33
  44
  58
  59
  61
  61
  93
  93
  97
 115
 207
 282
 213
 544
 665

MEAN VALUE = 0.0
SDEV = 241.952
MIN VALUE = -577
MAX VALUE = 665
RANGE = 1242
```

DATA FILENAME MODEL9

```
-194
-112
 -83
 -70
   0
 111
 132
 285
 321
 429
```

MEAN VALUE = 81.9
SDEV = 198.229
MIN VALUE = -194
MAX VALUE = 429
RANGE = 623

DATA FILENAME PERSIST9

```
-248
-143
 -26
  40
  67
  71
  92
  99
 153
 168
```

MEAN VALUE = 27.3
SDEV = 124.982
MIN VALUE = -248
MAX VALUE = 168
RANGE = 416

DATA FILENAME MODEL10

-603
-548
-538
-422
-383
-272
-214
-211
-194
-179
-112
-97
-84
-83
-70
-2
0
81
159
325
579
652
810
881
1098

MEAN VALUE = 22.92
SDEV = 450.575
MIN VALUE = -603
MAX VALUE = 1098
RANGE = 1701

DATA FILENAME PERSIST10

```
-1005
 -577
 -484
 -418
 -257
 -243
 -143
 -111
  -89
  -26
  -23
  -12
   -2
   20
   67
   81
   93
   93
   97
  153
  159
  168
  282
  544
  665
```

MEAN VALUE = -38.72
SDEV = 335.521
MIN VALUE = -1005
MAX VALUE = 665
RANGE = 1670

DATA FILENAME MODEL11

-560	-401
-252	-234
-234	-211
-170	-124
-89	-50
-28	-15
-7	-5
12	15
16	16
38	66
73	80
92	111
111	132
150	189
201	210
235	266
285	295
321	351
378	394
429	446
543	549
566	1971

MEAN VALUE = 140.023
SDEV = 372.330
MIN VALUE = -560
MAX VALUE = 1971
RANGE = 2531

DATA FILENAME PERSIST11

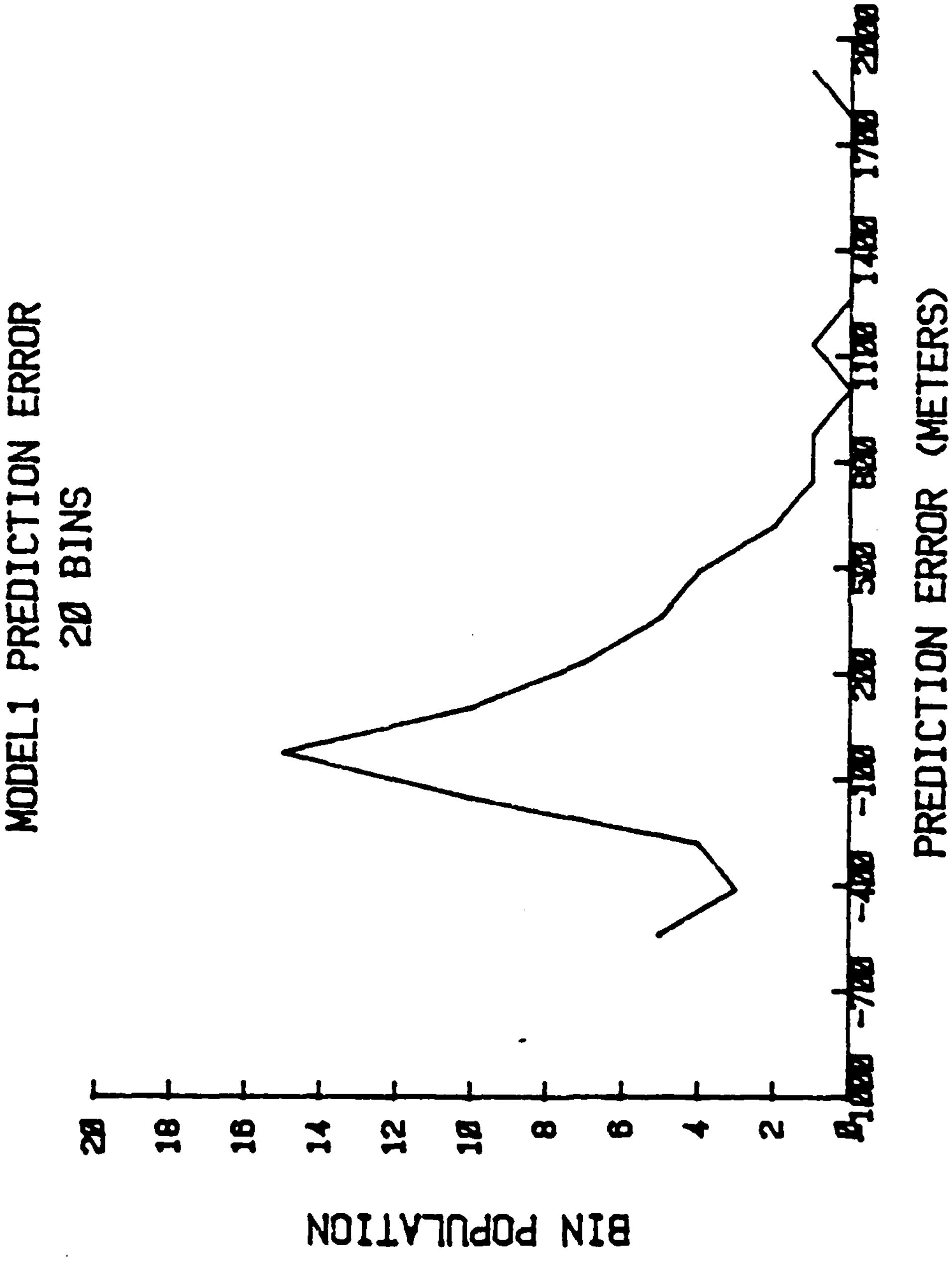
-782	-356
-248	-214
-214	-163
-155	-114
-110	-107
-102	-76
-57	-45
-42	-30
-29	-25
-17	-9
-5	-4
-3	30
32	33
40	44
54	58
59	61
62	71
92	99
115	169
169	177
190	207
312	1180

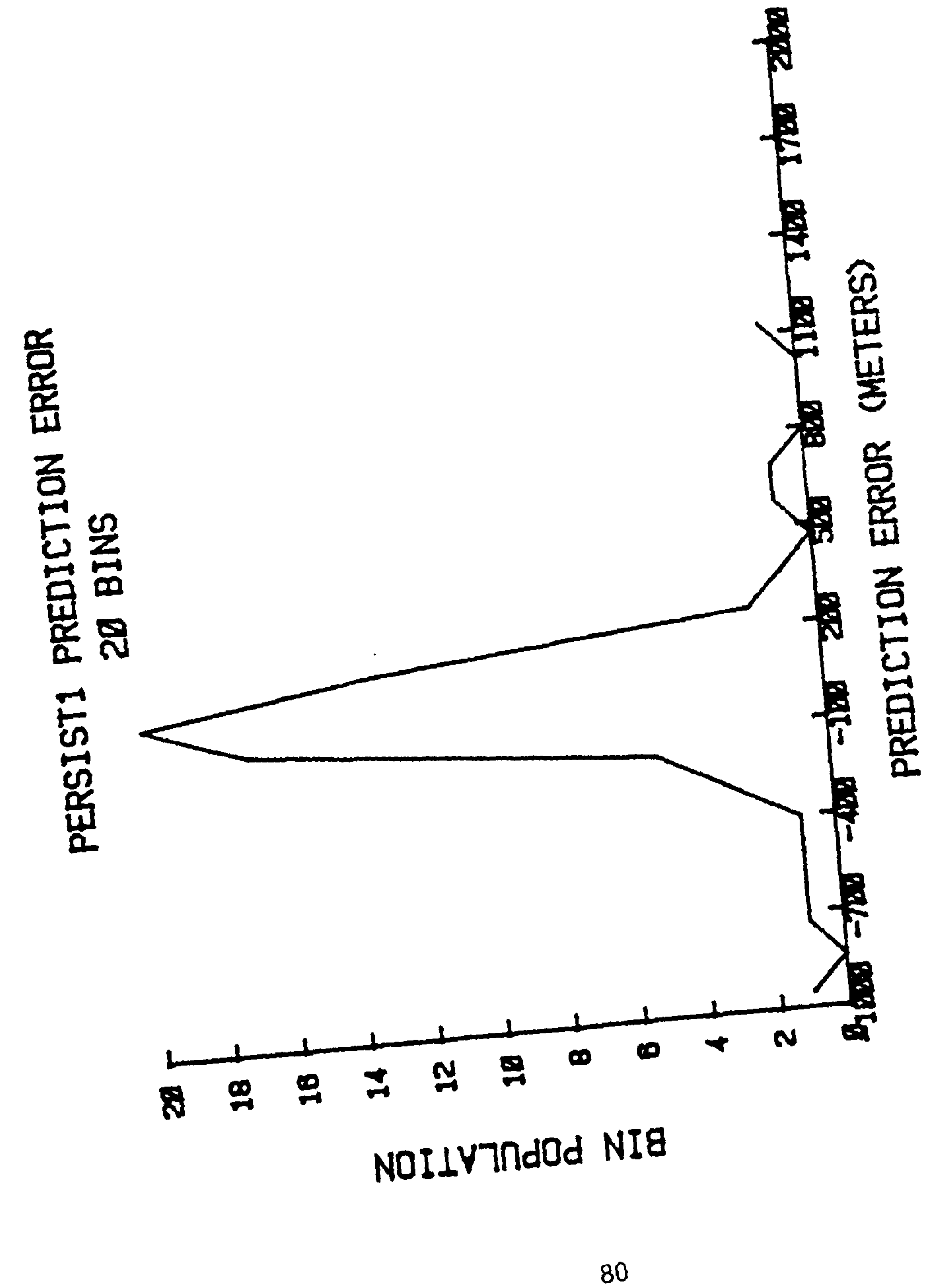
MEAN VALUE = 7.886
SDEV = 248.601
MIN VALUE = -782
MAX VALUE = 1180
RANGE = 1962

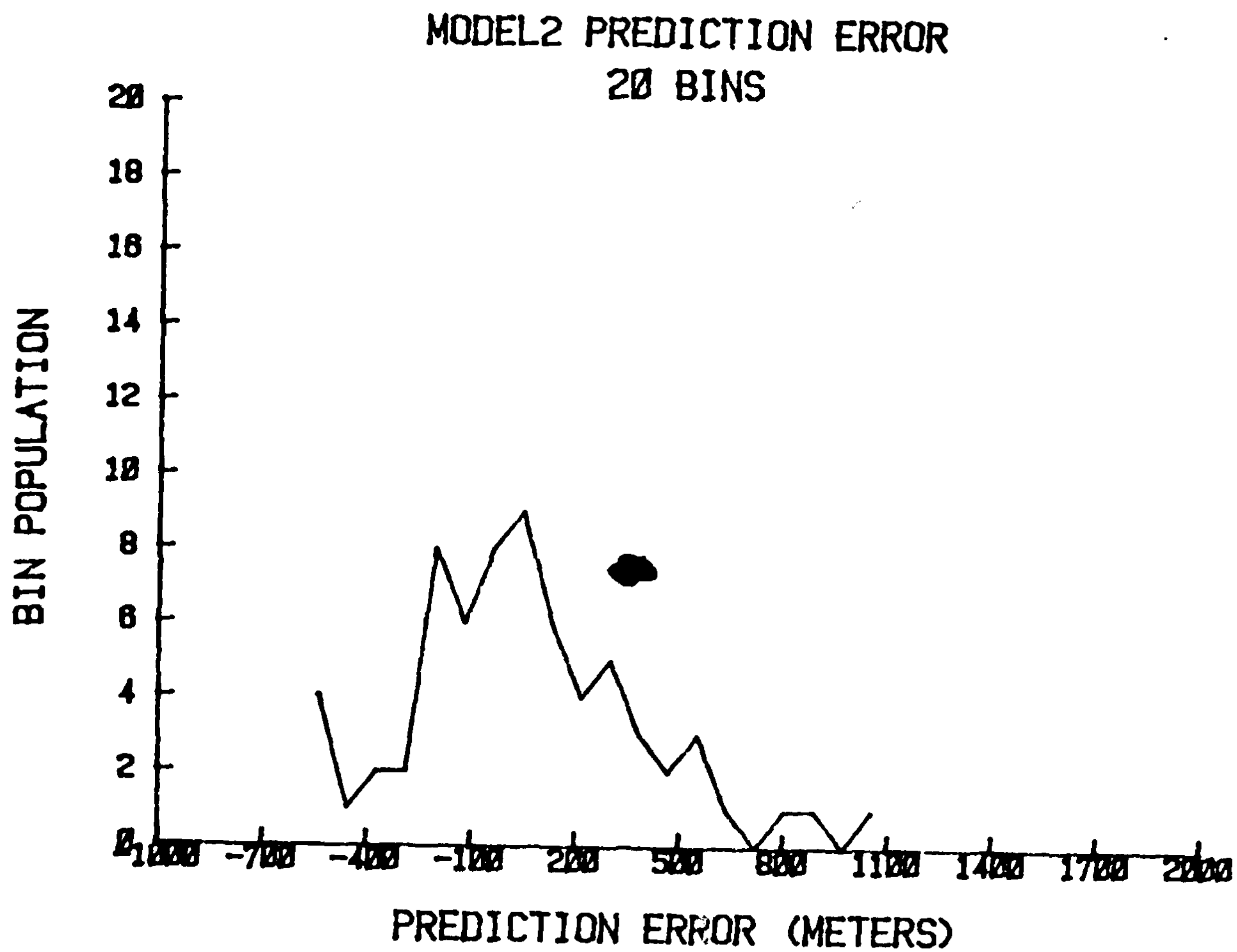
APPENDIX C

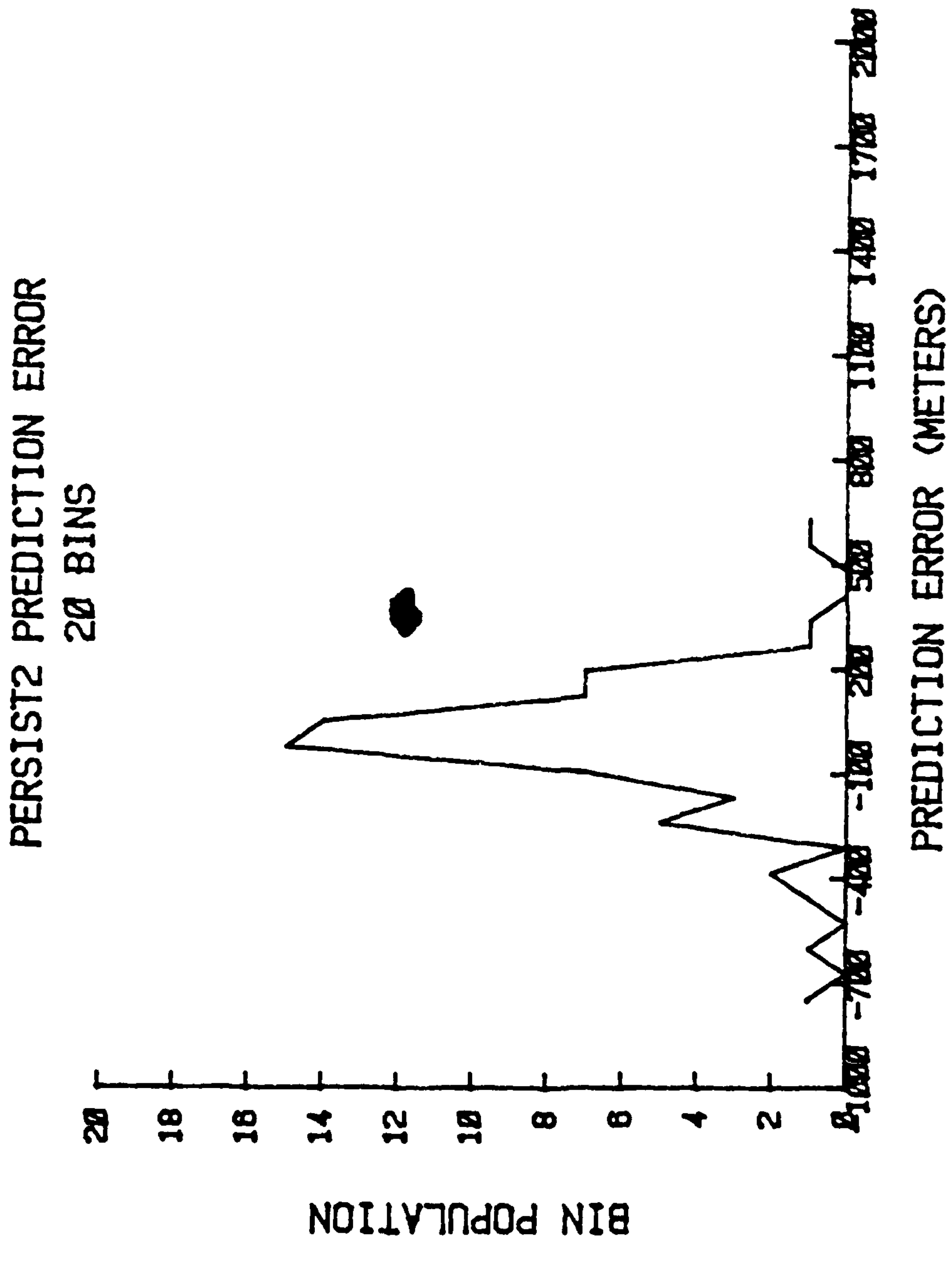
HISTOGRAMS OF PREDICTION ERRORS

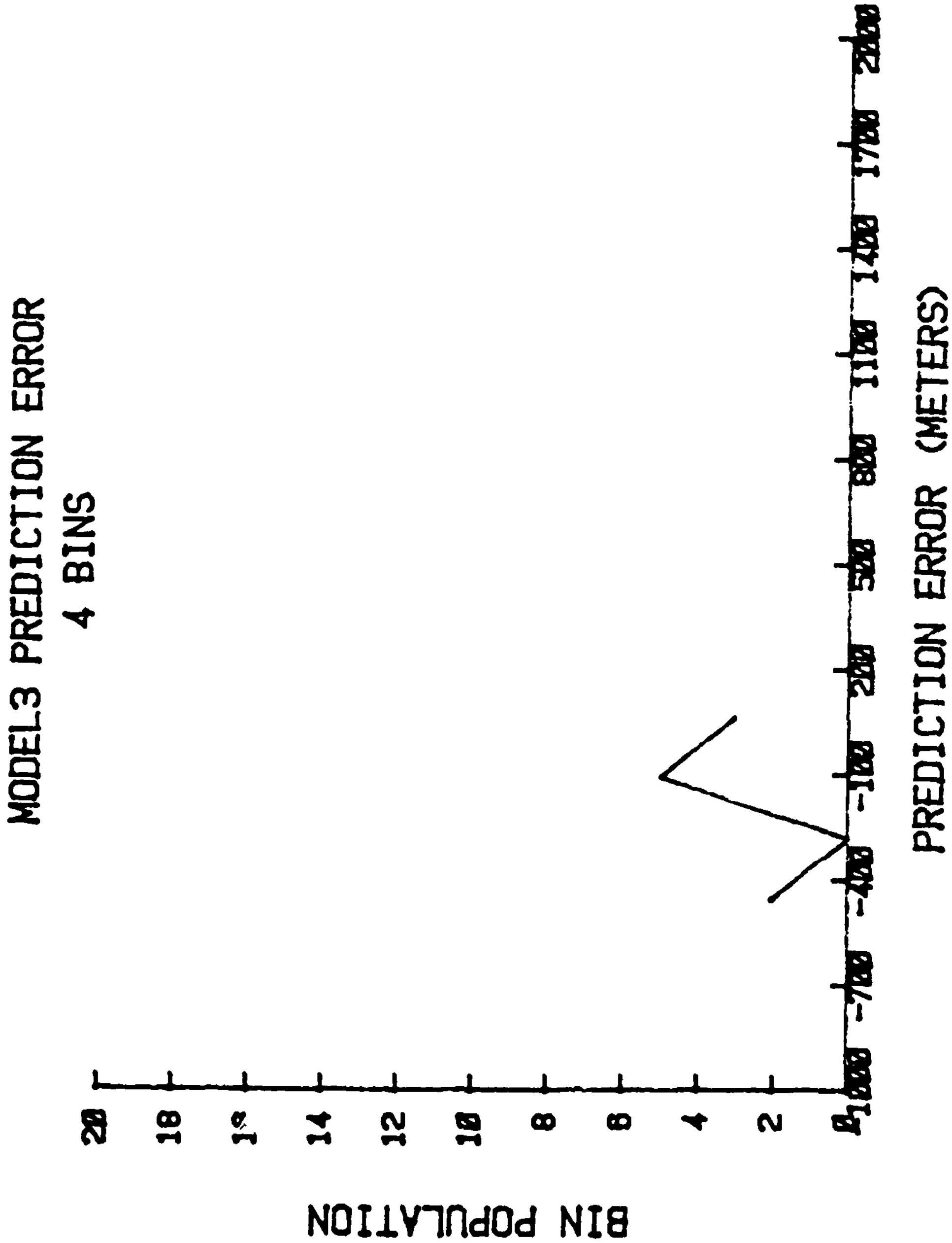
The following pages are histograms of the prediction errors. These plots show the distribution of each data set. The number of bins were chosen such that there were at least two data points per bin whenever possible.

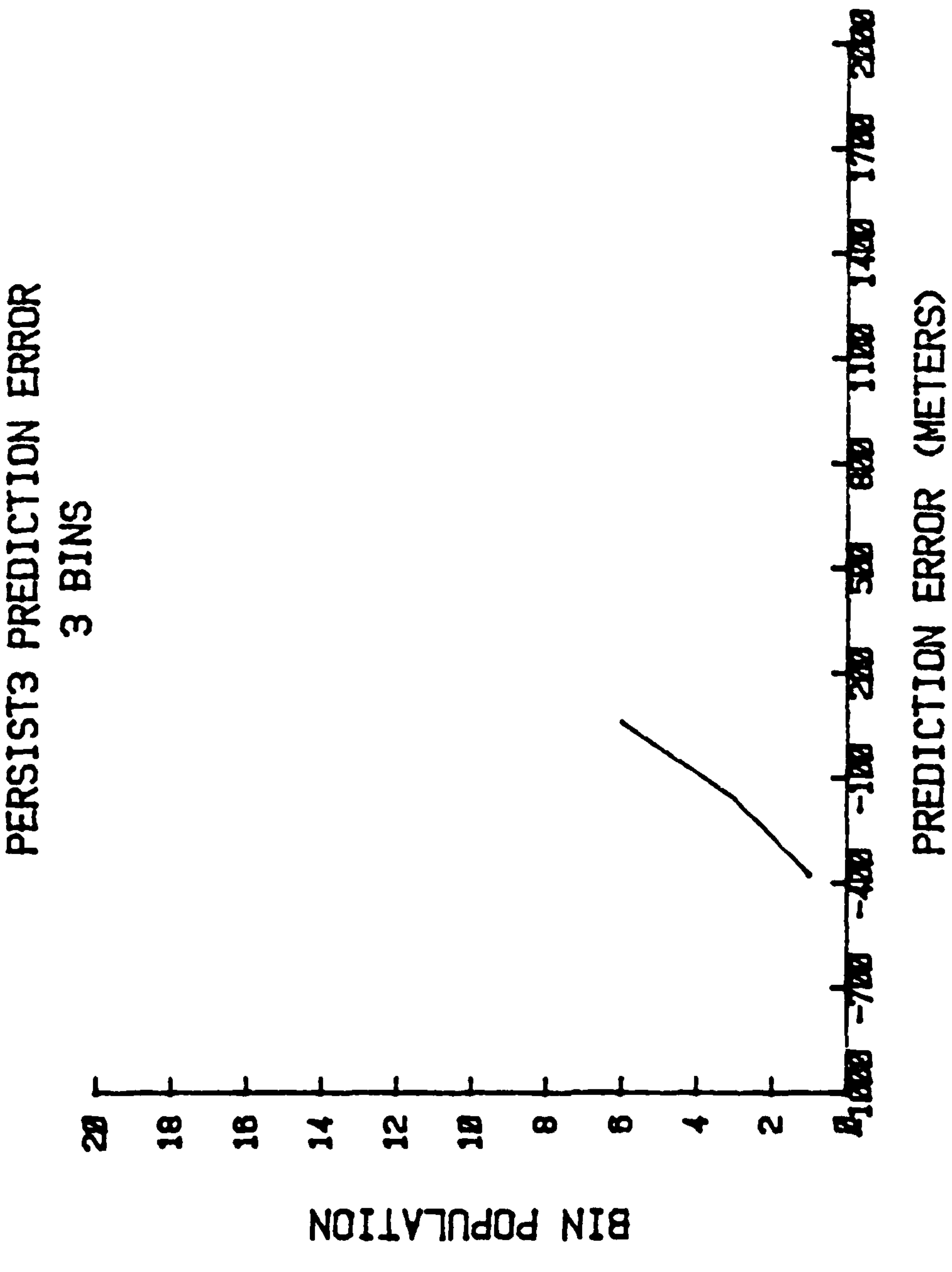

MODEL1 PREDICTION ERROR
2Ø BINS
BIN POPULATION
PREDICTION ERROR (METERS)
Ø
2
4
6
8
1Ø
12
14
16
18
2Ø
-1ØØØ
-7ØØ
-4ØØ
-1ØØ
2ØØ
5ØØ
8ØØ
11ØØ
14ØØ
17ØØ
2ØØØ

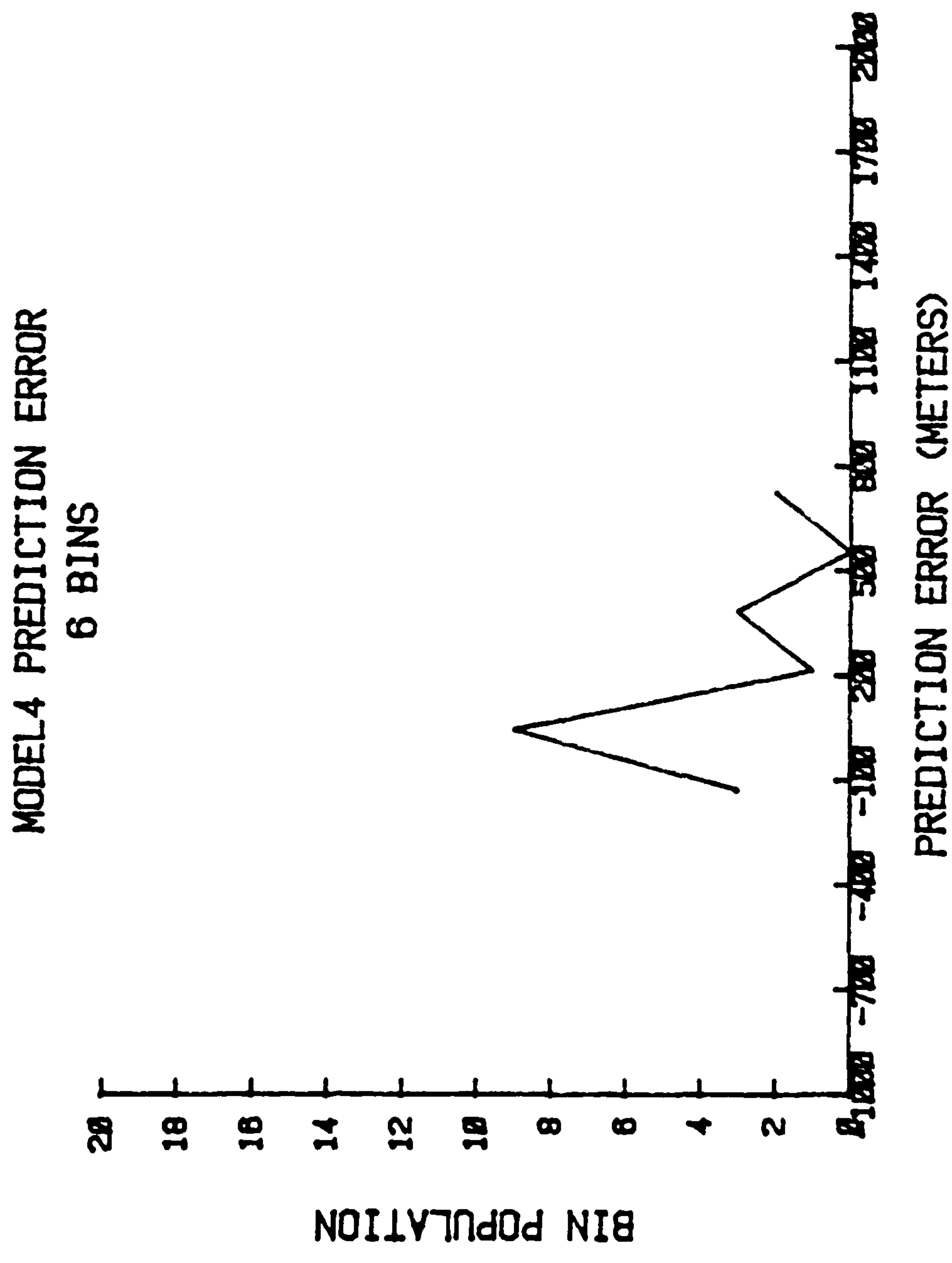

PERSIST1 PREDICTION ERROR
20 BINS
PREDICTION ERROR (METERS)
BIN POPULATION
0
2
4
6
8
10
12
14
16
18
20
-1000
-700
-400
-100
200
500
800
1100
1400
1700
2000

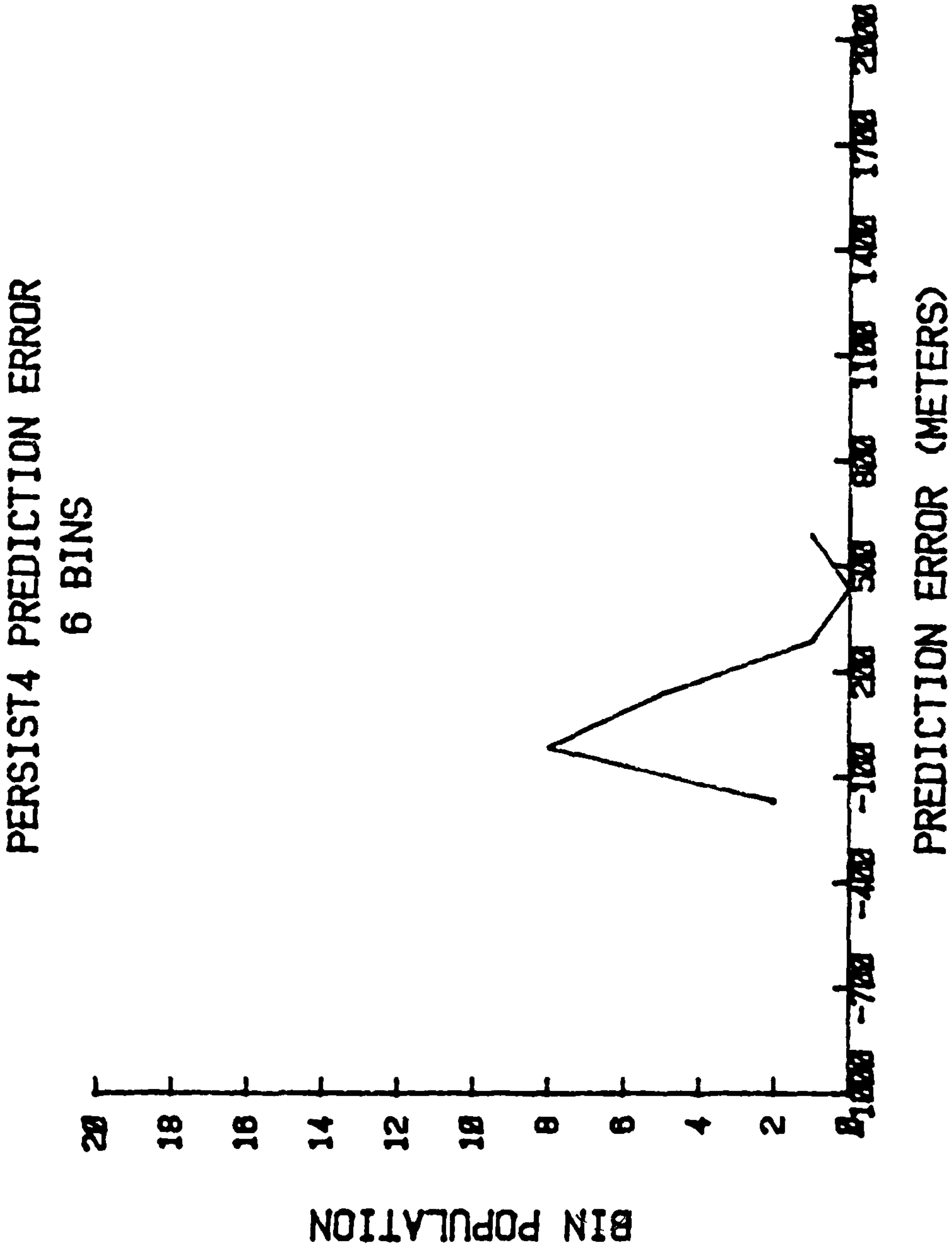

MODEL2 PREDICTION ERROR
20 BINS
BIN POPULATION
0
2
4
6
8
10
12
14
16
18
20
-1000
-700
-400
-100
200
500
800
1100
1400
1700
2000
PREDICTION ERROR (METERS)

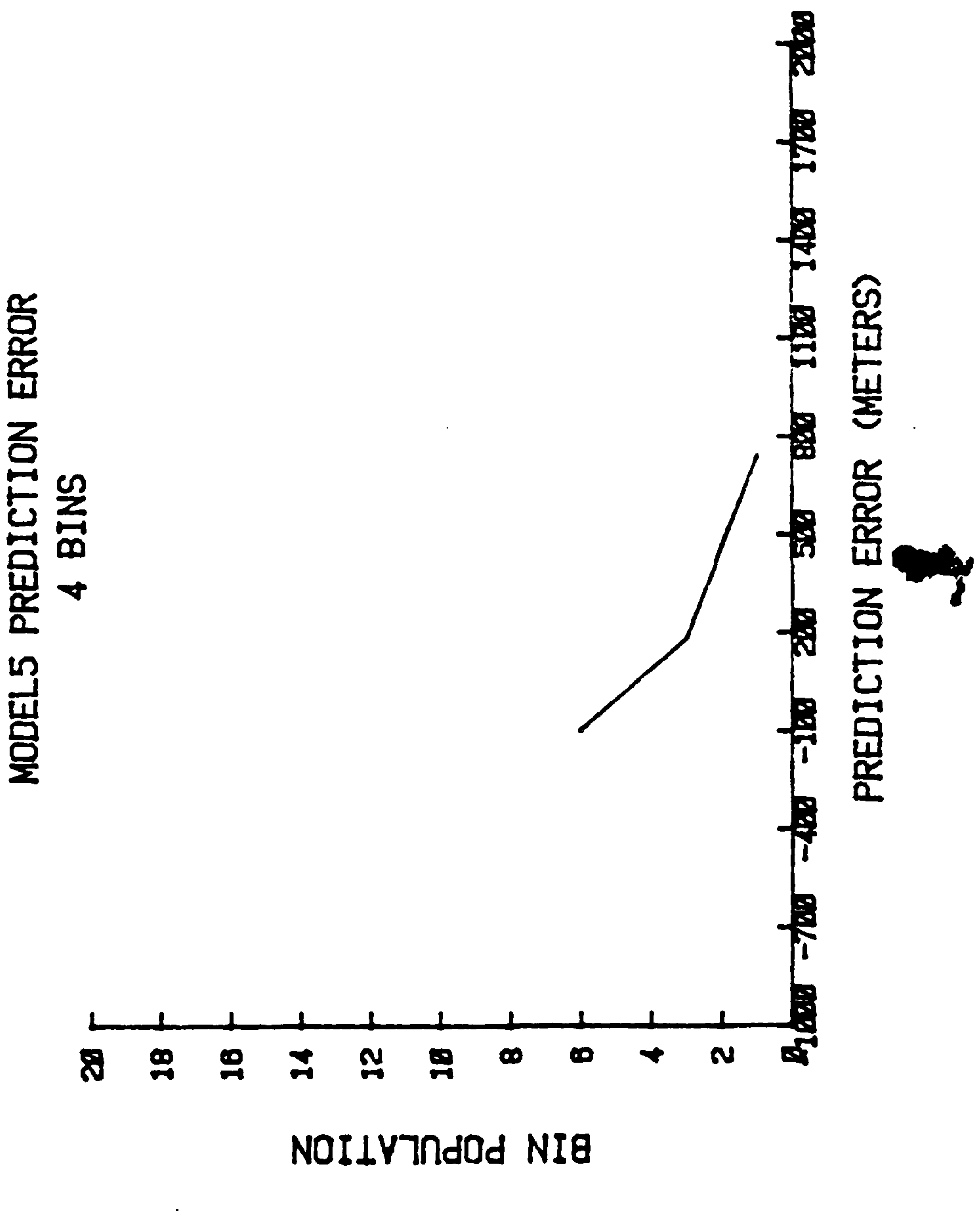

PERSIST2 PREDICTION ERROR
20 BINS
BIN POPULATION
PREDICTION ERROR (METERS)

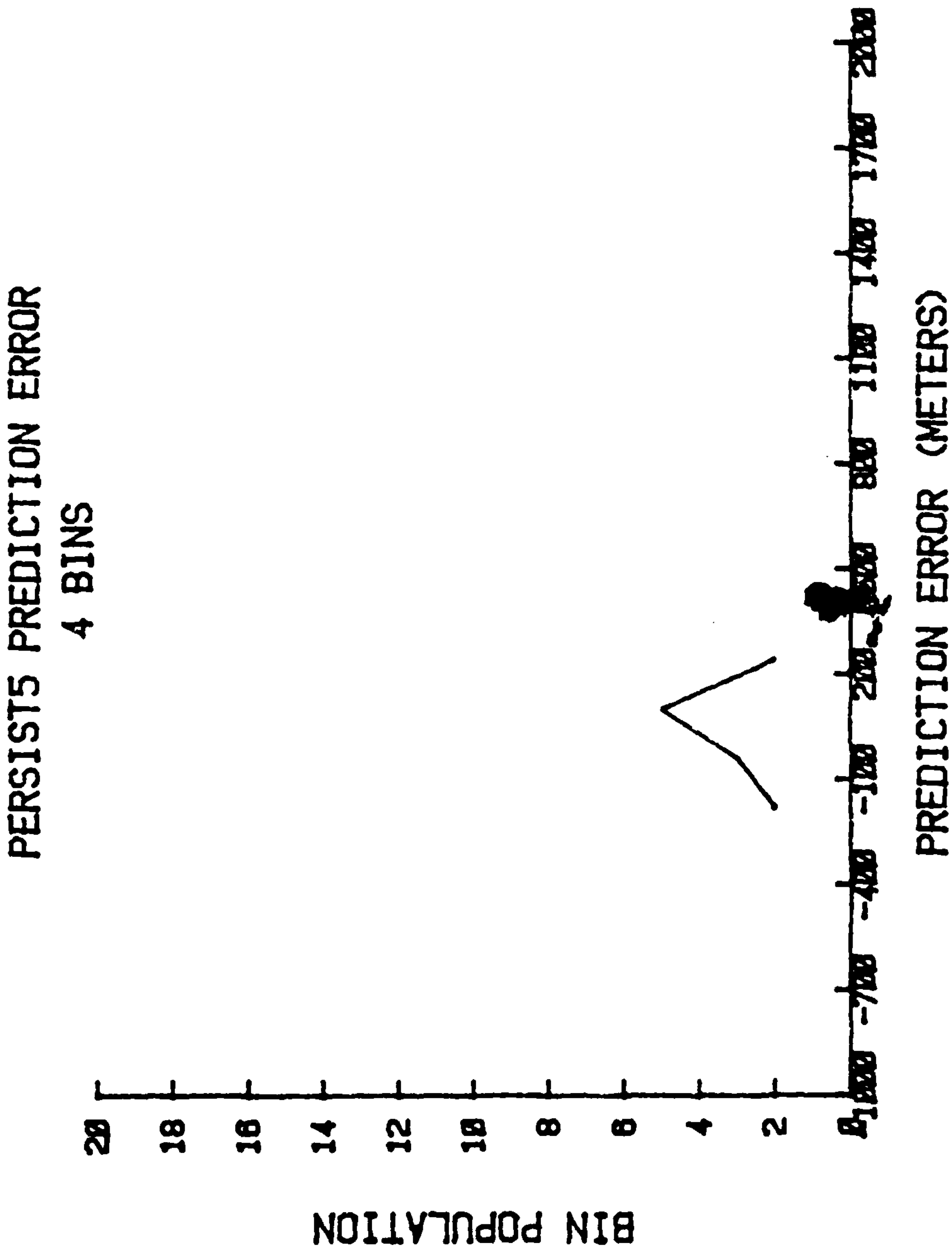

MODEL3 PREDICTION ERROR
4 BINS
PREDICTION ERROR (METERS)
BIN POPULATION
-1000
-700
-400
-100
200
500
800
1100
1400
1700
2000
0
2
4
6
8
10
12
14
18
20

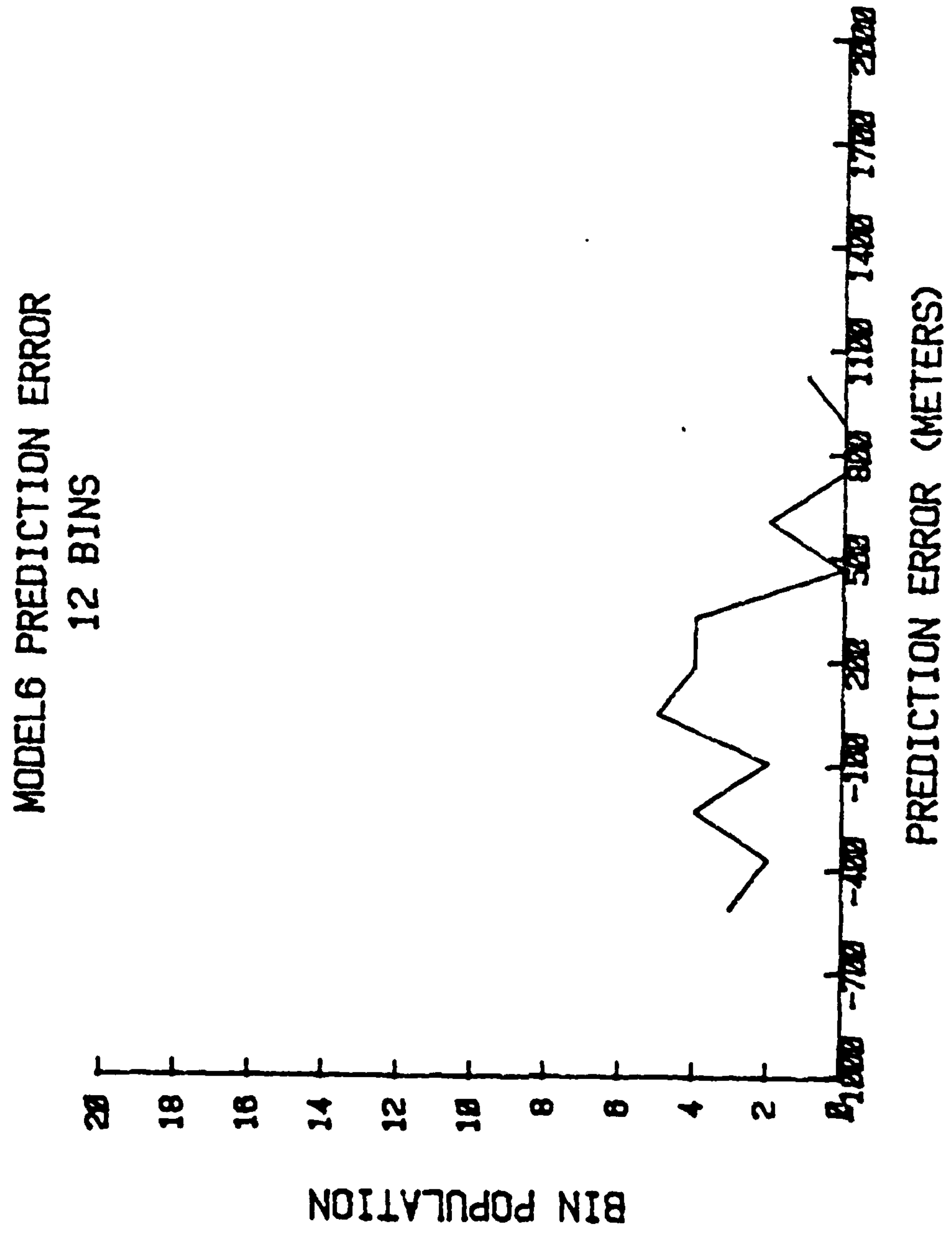

PERSIST3 PREDICTION ERROR
3 BINS
PREDICTION ERROR (METERS)
BIN POPULATION

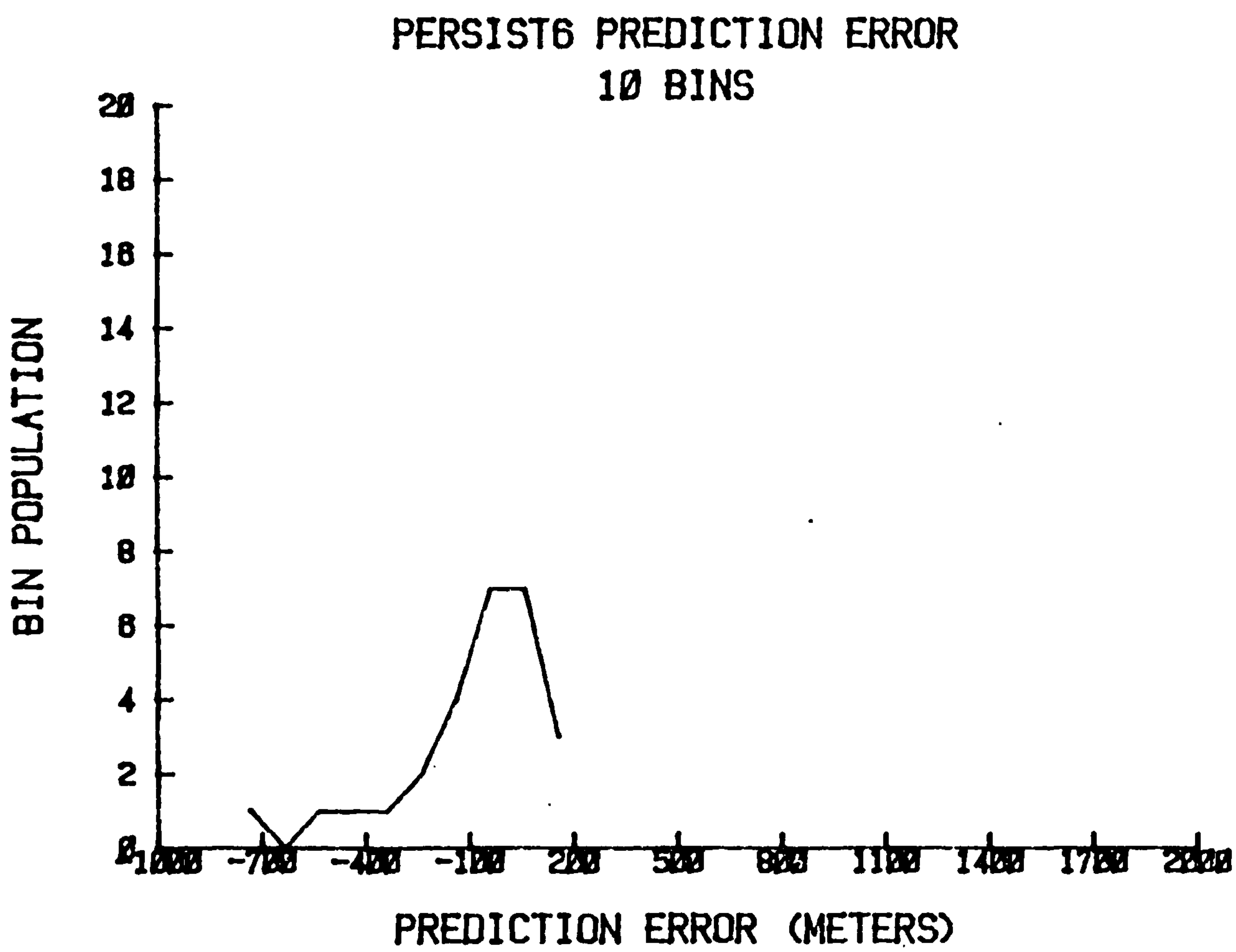

MODEL4 PREDICTION ERROR
6 BINS
BIN POPULATION
0
2
4
6
8
10
12
14
16
18
20
-1000
-700
-400
-100
200
500
800
1100
1400
1700
2000
PREDICTION ERROR (METERS)

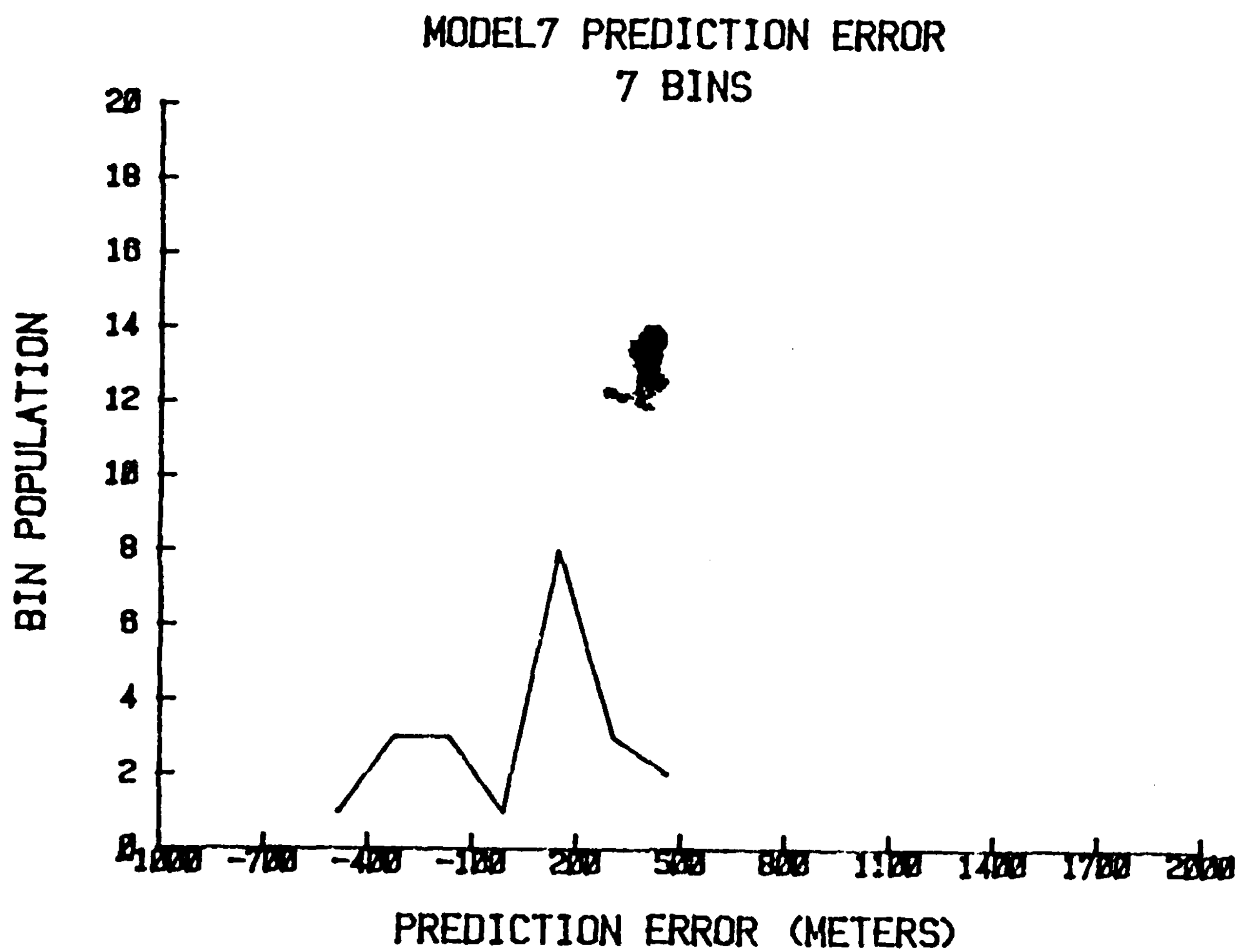

PERSIST4 PREDICTION ERROR
6 BINS
PREDICTION ERROR (METERS)
BIN POPULATION
-1000 -700 -400 -100 200 500 800 1100 1400 1700 2000
0 2 4 6 8 10 12 14 16 18 20

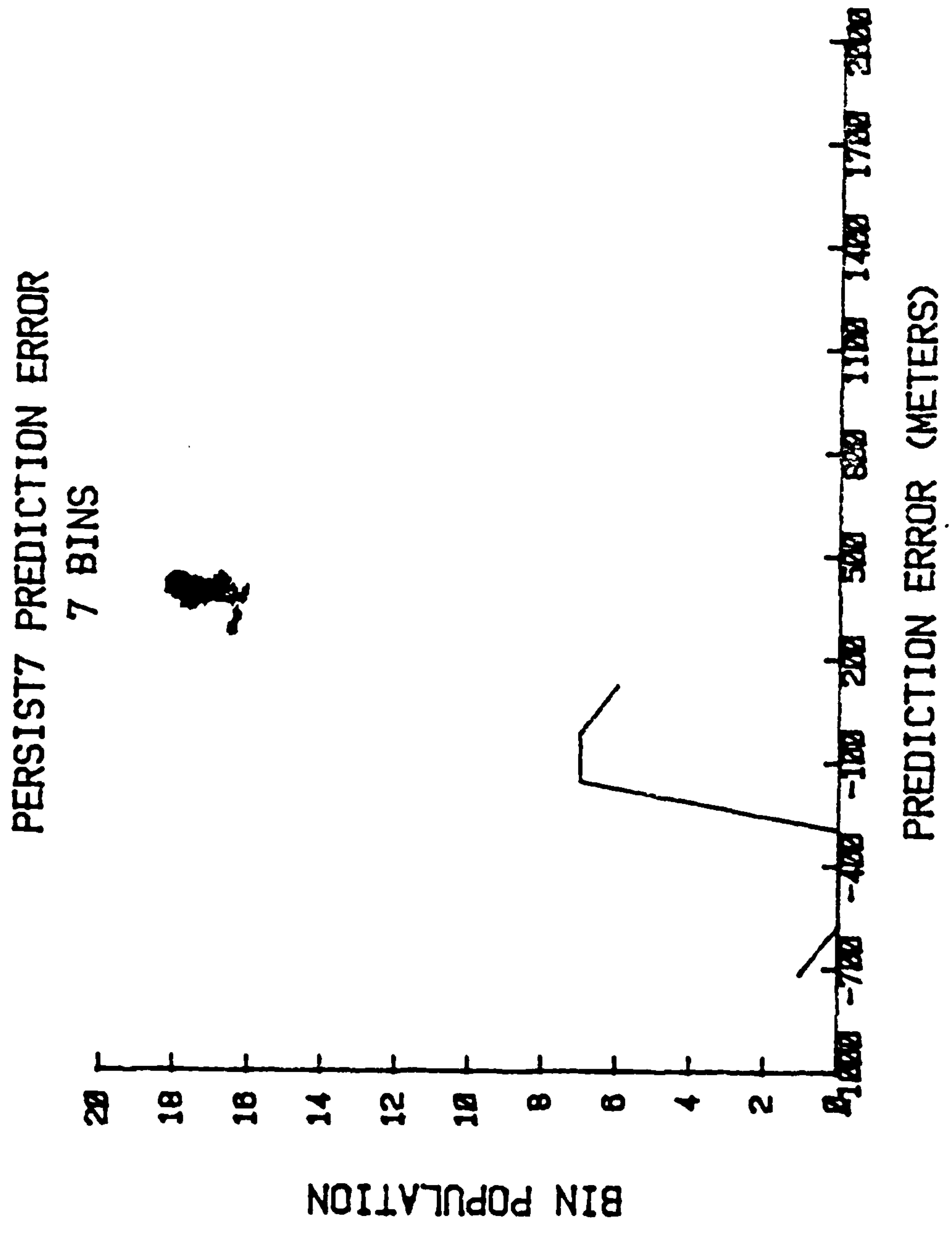

MODEL5 PREDICTION ERROR
4 BINS
BIN POPULATION
0
2
4
6
8
10
12
14
16
18
20
PREDICTION ERROR (METERS)
-1000
-700
-400
-100
200
500
800
1100
1400
1700
2000

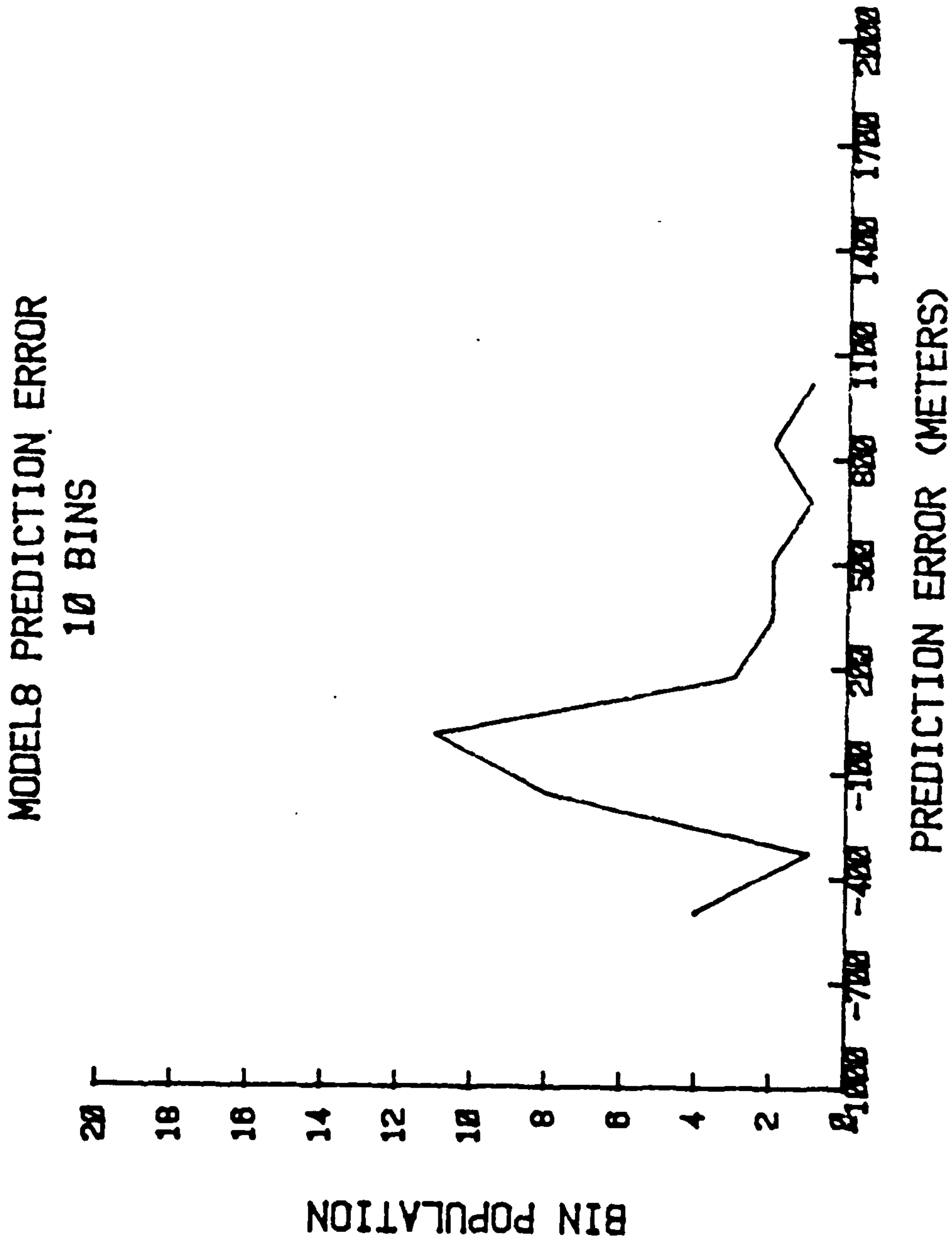

PERSISTS PREDICTION ERROR
4 BINS
BIN POPULATION
PREDICTION ERROR (METERS)

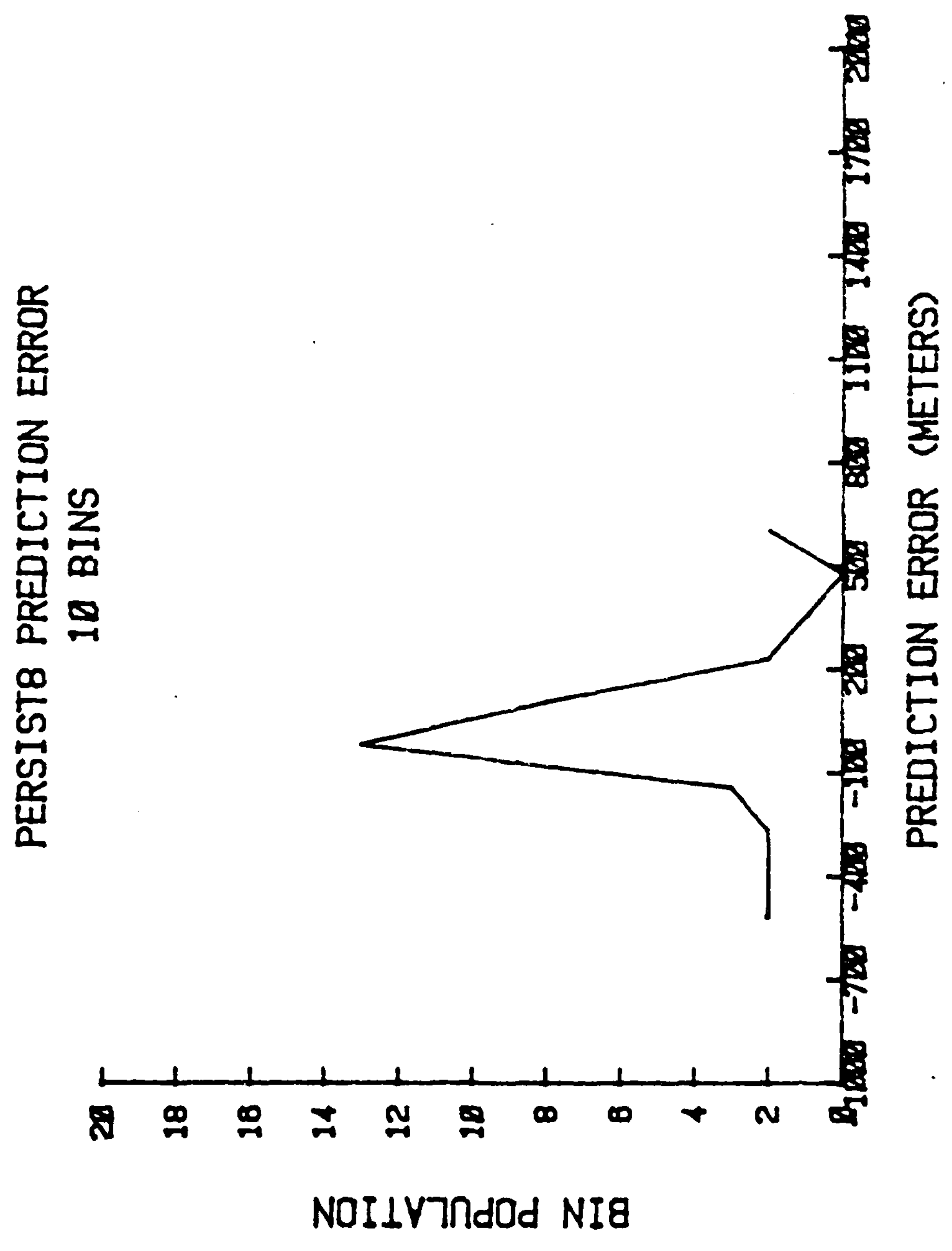

MODEL6 PREDICTION ERROR
12 BINS
BIN POPULATION
0
2
4
6
8
10
12
14
16
18
20
-1000
-700
-400
-100
200
500
800
1100
1400
1700
2000
PREDICTION ERROR (METERS)


PERSIST6 PREDICTION ERROR
10 BINS
BIN POPULATION
20
18
16
14
12
10
8
6
4
2
0
-1000
-700
-400
-100
200
500
800
1100
1400
1700
2000
PREDICTION ERROR (METERS)


MODEL7 PREDICTION ERROR
7 BINS
BIN POPULATION
20
18
16
14
12
10
8
6
4
2
0
-1000
-700
-400
-100
200
500
800
1100
1400
1700
2000
PREDICTION ERROR (METERS)


PERSIST7 PREDICTION ERROR
7 BINS
BIN POPULATION
PREDICTION ERROR (METERS)
0
2
4
6
8
10
12
14
16
18
20
-1000
-700
-400
-100
200
500
800
1100
1400
1700
2000


MODEL8 PREDICTION ERROR
10 BINS
BIN POPULATION
PREDICTION ERROR (METERS)
0
2
4
6
8
10
12
14
18
20
-1000
-700
-400
-100
200
500
800
1100
1400
1700
2000


PERSIST8 PREDICTION ERROR
10 BINS
BIN POPULATION
PREDICTION ERROR (METERS)

AD-A151 053 STATISTICAL/TREND ANALYSIS OF THE MARINE ATMOSPHERIC BOUNDARY LAYER MODEL(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA R D BISKING SEP 84 2/2

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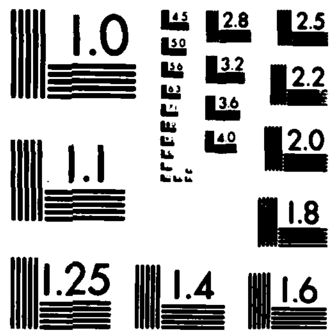
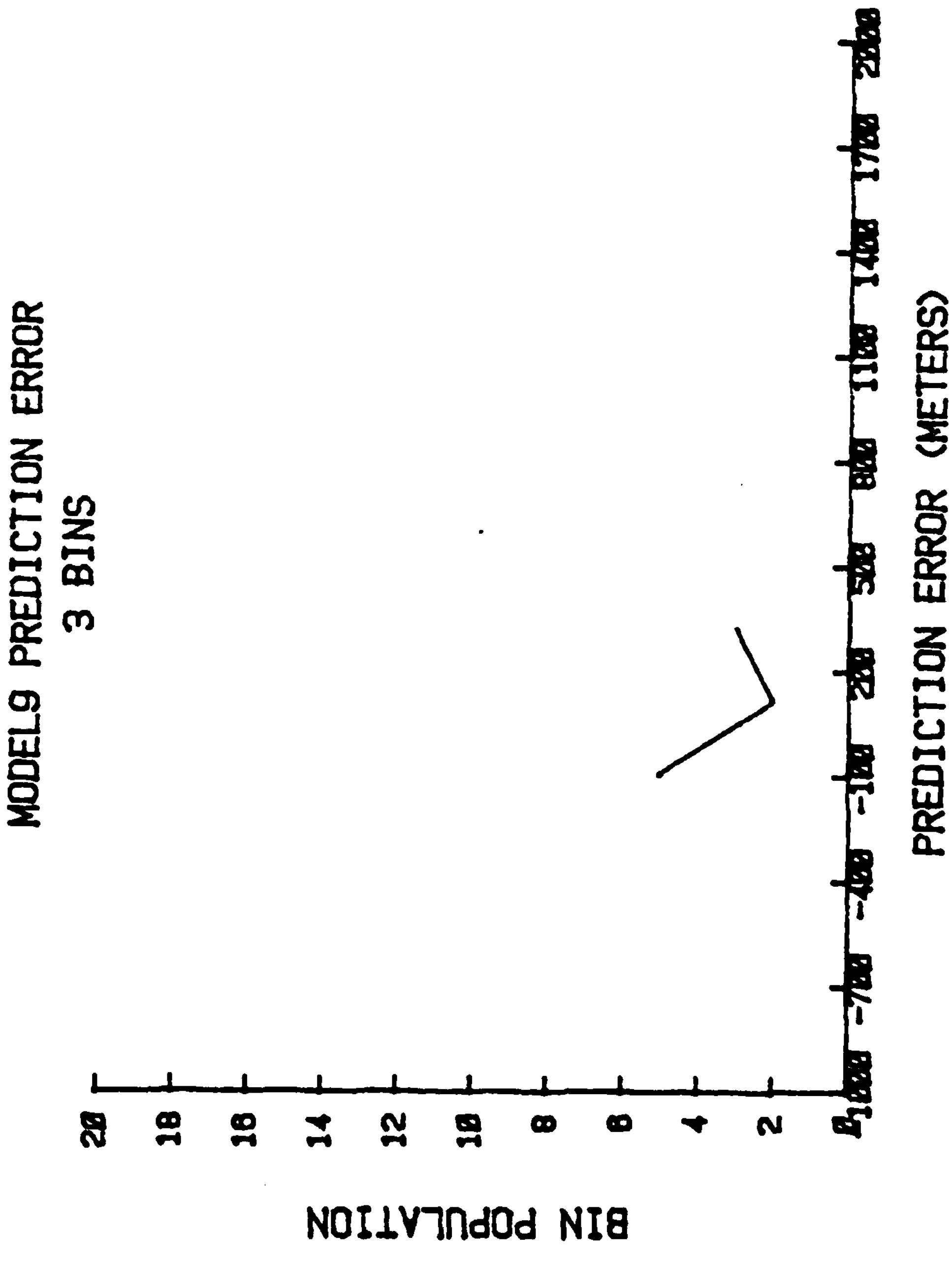
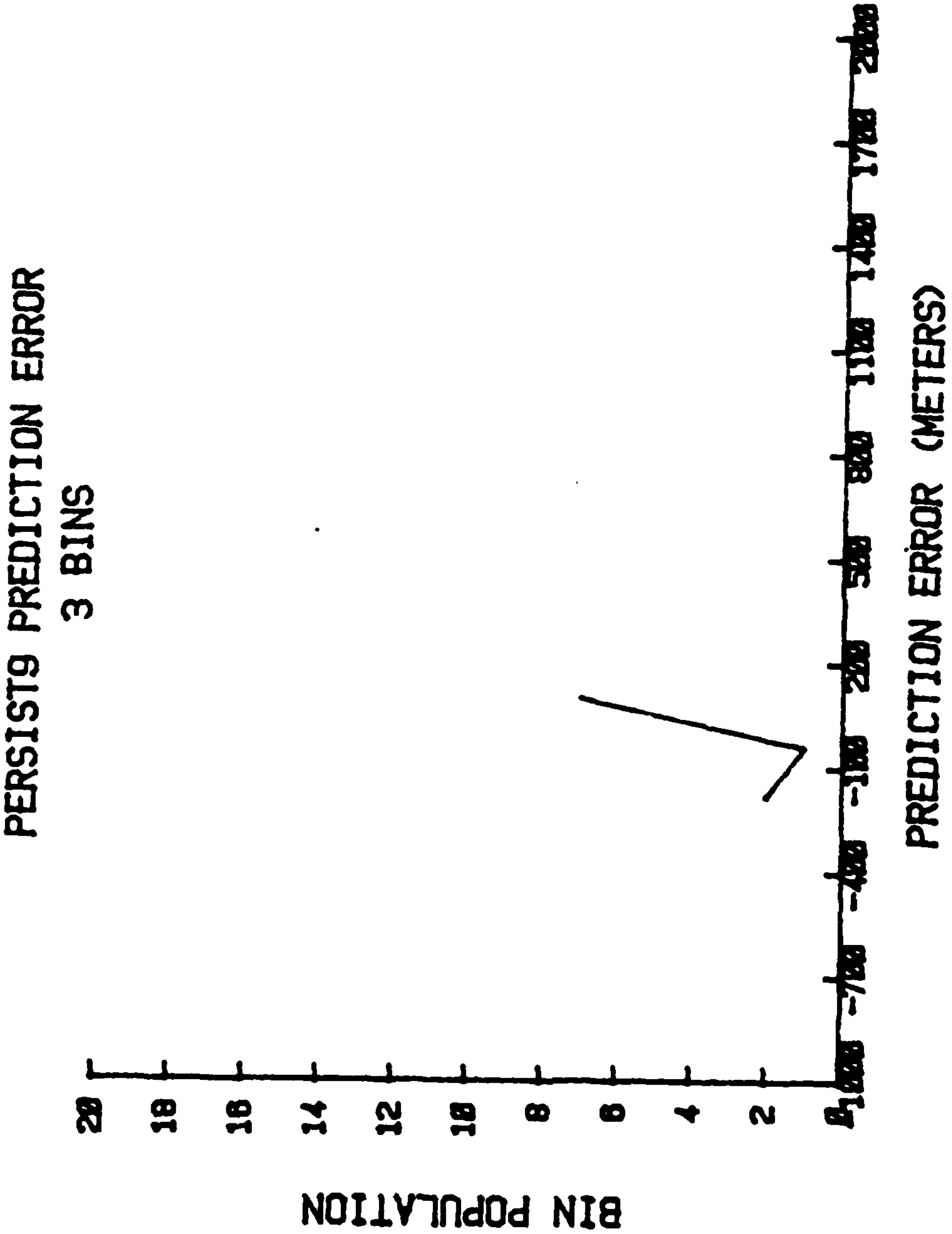
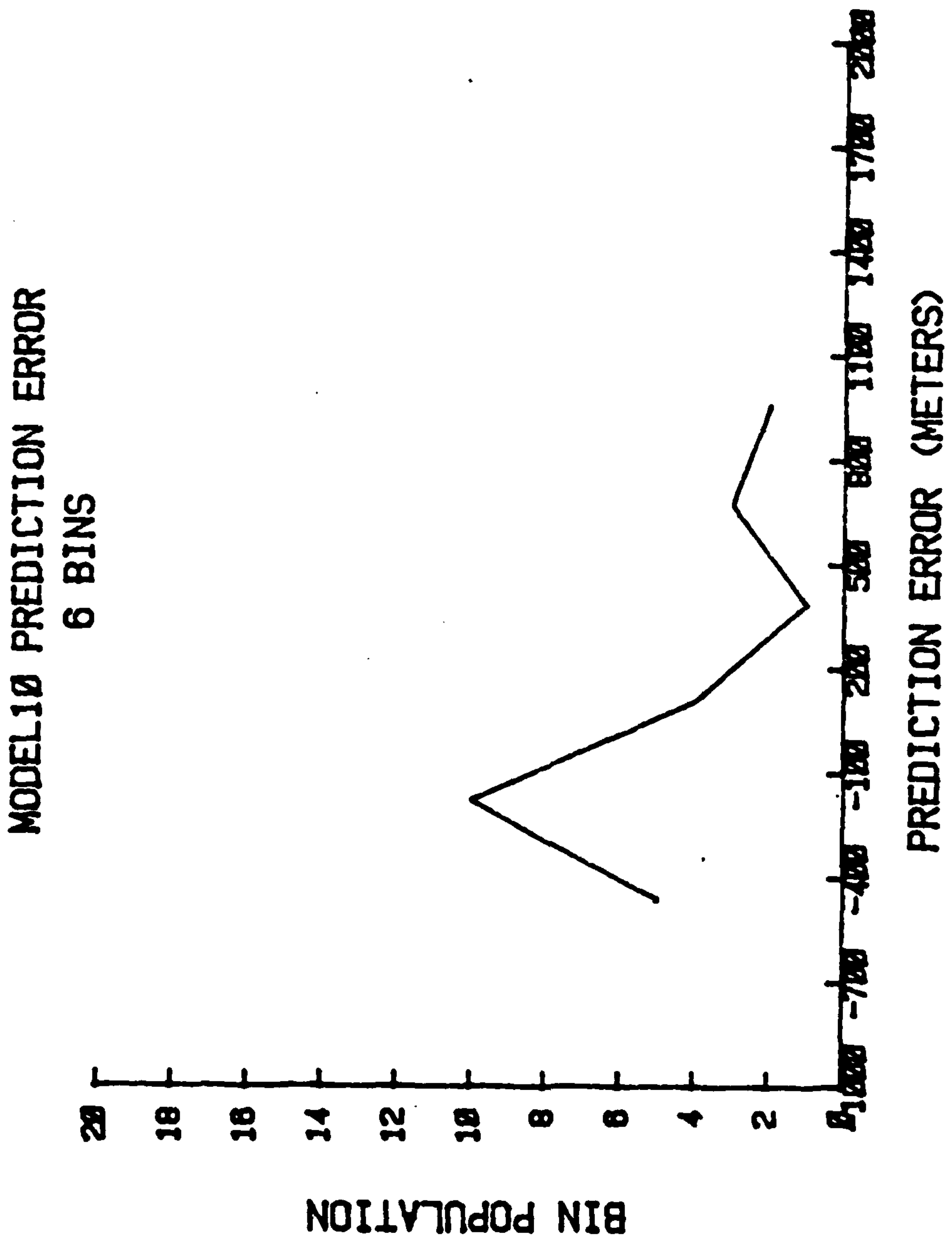
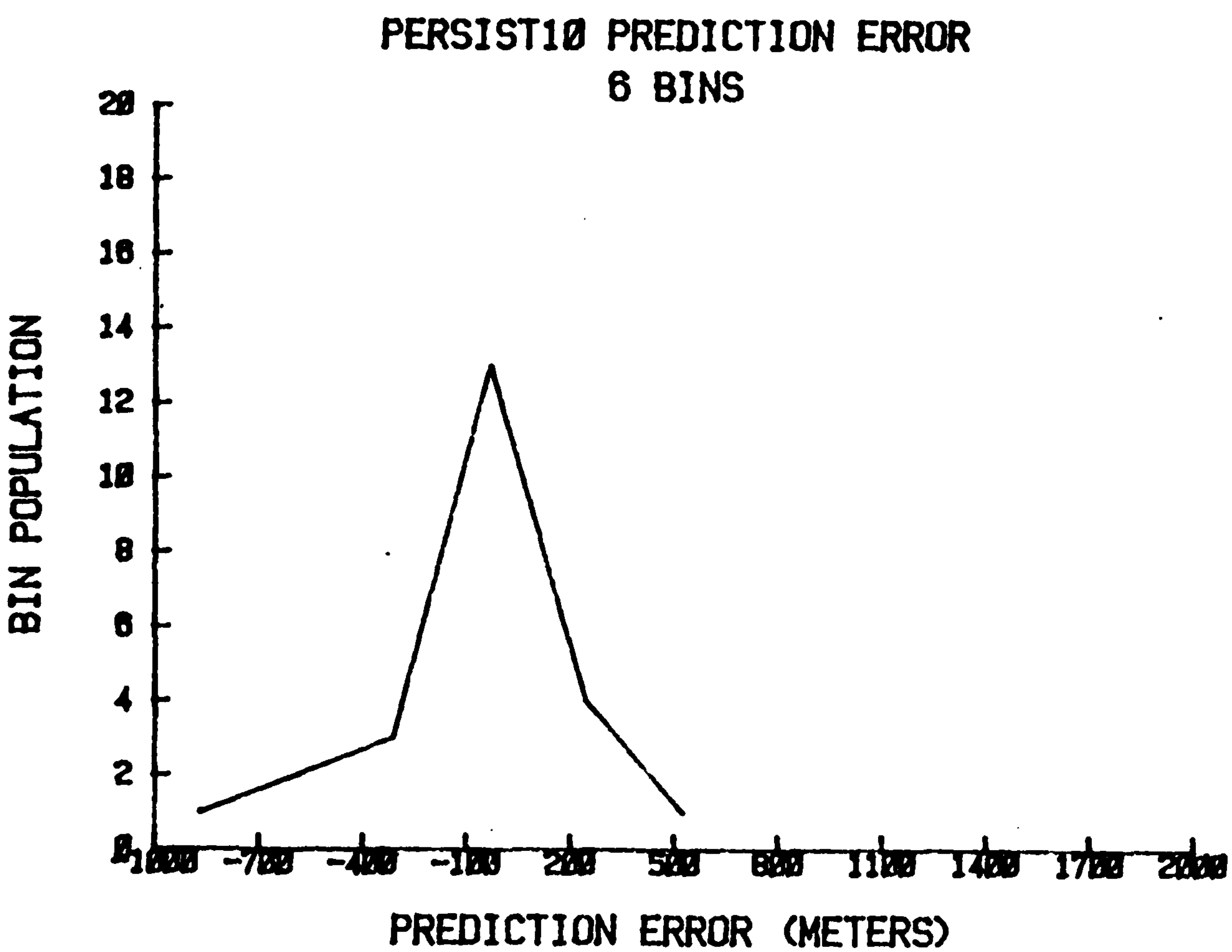


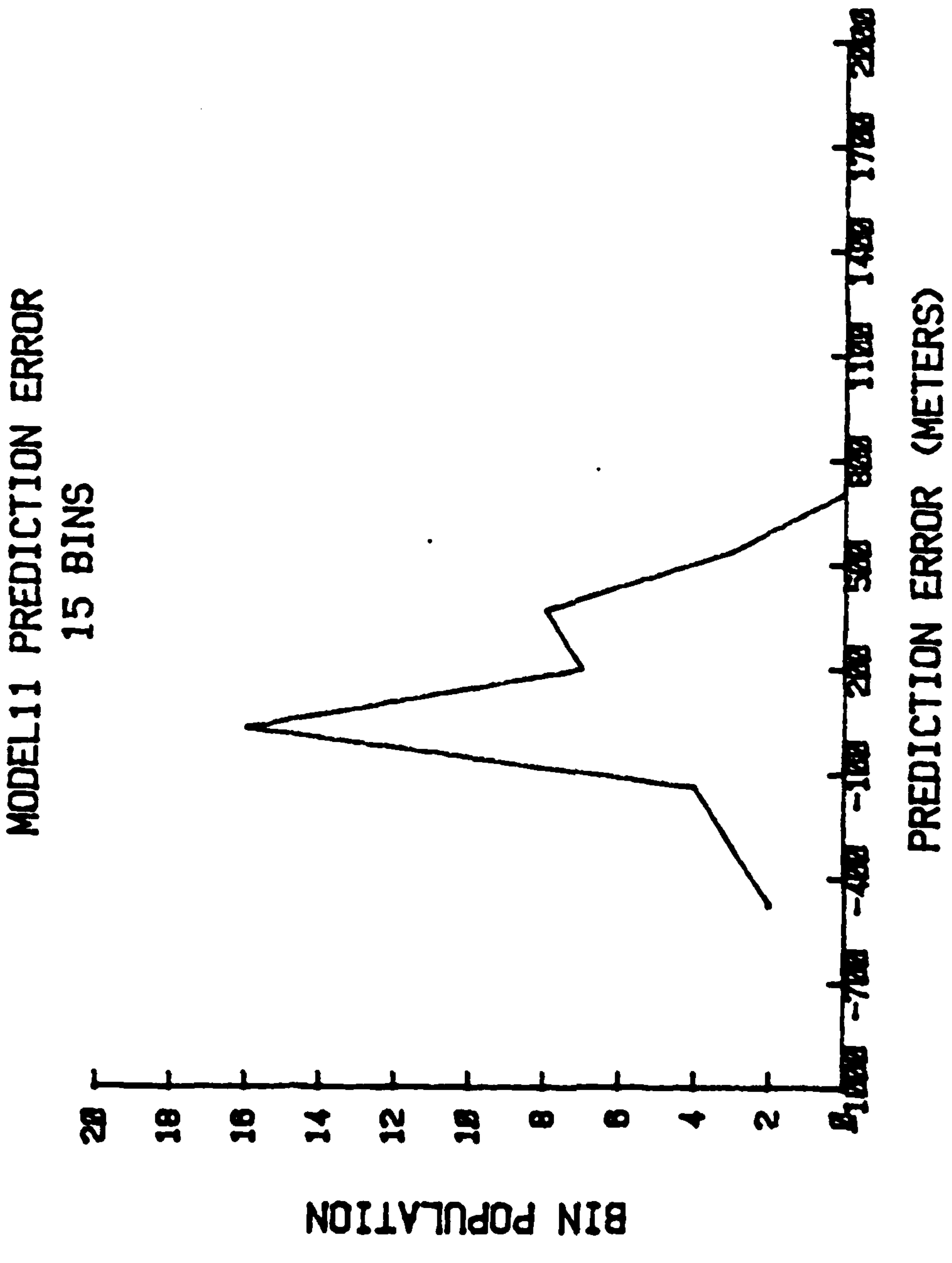
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

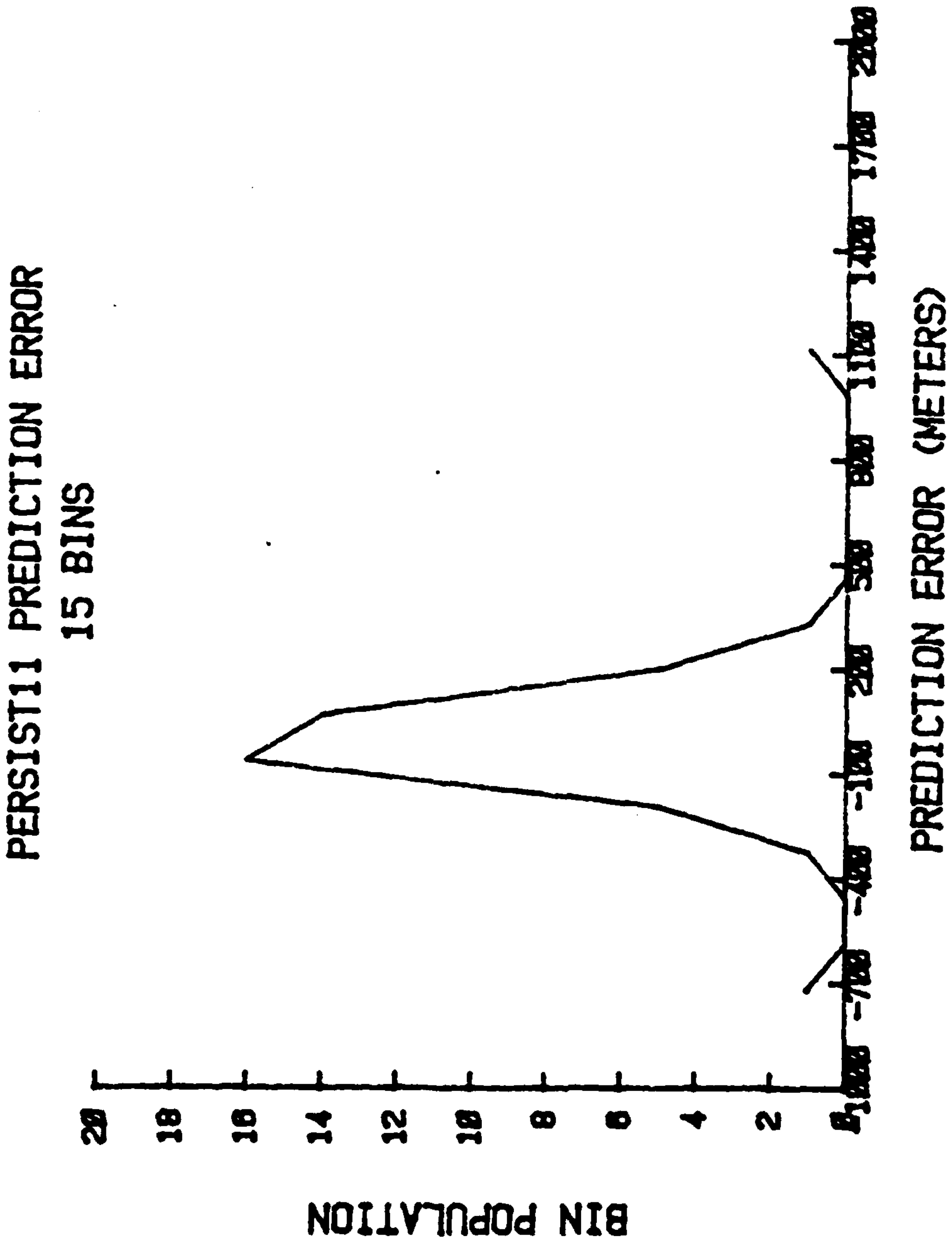

MODEL9 PREDICTION ERROR
3 BINS
PREDICTION ERROR (METERS)
BIN POPULATION


PERSIST9 PREDICTION ERROR
3 BINS
BIN POPULATION
0
2
4
6
8
10
12
14
16
18
20
-1000
-700
-400
-100
200
500
800
1100
1400
1700
2000
PREDICTION ERROR (METERS)


MODEL10 PREDICTION ERROR
6 BINS
BIN POPULATION
PREDICTION ERROR (METERS)


PERSIST10 PREDICTION ERROR
6 BINS
BIN POPULATION
0
2
4
6
8
10
12
14
16
18
20
-1000
-700
-400
-100
200
500
800
1100
1400
1700
2000
PREDICTION ERROR (METERS)


MODEL11 PREDICTION ERROR
15 BINS
BIN POPULATION
PREDICTION ERROR (METERS)
0
2
4
6
8
10
12
14
16
18
20
-1000
-700
-400
-100
200
500
800
1100
1400
1700
2000


PERSIST11 PREDICTION ERROR
15 BINS
PREDICTION ERROR (METERS)
BIN POPULATION

APPENDIX D

DELTA M - DELTA P VALUES

The following pages contain the data sets used in the paired sample t test. These values were obtained by subtracting from Delta M the corresponding Delta P value.

DATA FILENAME PAIRED1

-493	-403	-325
-307	-270	-251
-235	-225	-223
-165	-130	-124
-120	-96	-95
-86	-84	-72
-67	-54	-51
-46	-20	-14
-9	-6	17
24	27	28
31	33	39
40	42	44
46	52	64
71	89	97
124	129	140
145	166	190
194	222	222
237	256	267
270	320	349
352	358	366
397	402	533
565	573	784
791	1017	1156

MEAN VALUE = 106.594
SDEV = 304.526
MIN VALUE = -493
MAX VALUE = 1156
RANGE = 1649

DATA FILENAME PAIRED2

-403	-325	-307
-270	-251	-235
-225	-223	-165
-130	-124	-109
-96	-95	-86
-84	-72	-67
-54	-51	-46
-20	-14	-8
-6	17	24
27	28	31
33	38	40
40	44	46
52	64	71
88	97	104
108	140	145
155	180	194
222	222	237
256	267	270
320	349	352
358	366	397
402	533	565
673	784	791
1017		

MEAN VALUE = 99.881
SDEV = 271.398
MIN VALUE = -403
MAX VALUE = 1017
RANGE = 1420

DATA FILENAME PAIRED3

```
 -307
 -223
 -124
 -109
  -95
   17
  180
  237
  256
  267
  402
  533
  784
```

MEAN VALUE = 139.846
SDEV = 305.344
MIN VALUE = -307
MAX VALUE = 784
RANGE = 1091

DATA FILENAME PAIRED4

```
 -403
 -272
 -235
 -225
 -165
 -130
  -86
  -51
  -14
   -6
   27
   28
   33
   40
   52
   97
  222
  270
  320
  349
  352
  365
  397
  565
  673
  791
 1017
 1156
```

MEAN VALUE = 184.571
SDEV = 377.412
MIN VALUE = -403
MAX VALUE = 1156
RANGE = 1559

DATA FILENAME PAIREDS

-493
-307
-270
-225
-165
-130
-109
-95
-94
-72
-54
-46
-20
-14
-8
-6
17
24
27
28
33
40
52
64
108
140
145
180
237
320
349
673
784
1017
1156

MEAN VALUE = 94.171
SDEV = 340.108
MIN VALUE = -493
MAX VALUE = 1156
RANGE = 1649

DATA FILENAME PAIREDS

-325	-235
-223	-124
-109	-96
-84	-46
-20	-14
-6	17
24	27
28	31
33	38
40	40
44	46
52	71
88	97
140	180
194	222
222	237
256	267
322	349
352	358
366	397
533	565
673	791

MEAN VALUE = 132.182
SDEV = 231.451
MIN VALUE = -325
MAX VALUE = 791
RANGE = 1116

LIST OF REFERENCES

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